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Huckleberry Ecology and Management Research in the Pacific Northwest

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ABSTRACT

Big huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.) berry duction is declining in many northwestern huckleberry fields as they invaded by subalpine trees. Seeking ways to halt this invasion and rease berry production, the authors studied huckleberries in the ade Range of Oregon and Washington from 1972 through 1977. They eloped methods of growing huckleberries in the laboratory, tested eral methods of controlling competing vegetation in the field, and orded the changes in plant species composition and huckleberry pro- tion that resulted from applying these methods. This illustrated ort includes descriptions of the experiments performed, results, clusions, and management recommendations. It is a summary of the kleberry research accomplished by personnel of the Pacific North- Forest and Range Experiment Station during the 6-year study period.

KEYWORDS: Huckleberries, Vaccinium, succession, research.

CONTENTS

Page

INTRODUCTION. 1

FIELD RESEARCH IN THE MOUNT ADAMS AREA. 4
  History 4
  1972 Experiment 5
    Area Description 5
    Objectives 9
    Experimental Design. 9
    Treatments 9
    Data Collection and Processing 13
    Results. 14
    Conclusions. 22
  Additional Mount Adams Field Research 24

FIELD RESEARCH IN THE MOUNT HOOD AREA 25
  Area Description. 25
  Bulldoze-and-Burn Experiment. 26
    Objectives 26
    Experimental Design. 28
    Treatment. 28
    Data Collection and Processing 29
    Results. 29
    Conclusions. 29
  Karbutilate Experiment. 29
    Objective. 29
    Experimental Design. 29
    Treatments 32
    Data Collection and Processing 32
    Results. 32
    Conclusions. 34
  Five-Treatment Grid 34
    Objective. 34
    Experimental Design. 34
    Treatments 34
    Data Collection and Processing 36
    Results. 36
    Conclusions. 41

LABORATORY RESEARCH 43

DISCUSSION. 45

MANAGEMENT RECOMMENDATIONS. 47

LITERATURE CITED. 49

INTRODUCTION

For centuries before men learned to prevent and control them, wildfires periodically raced through northwestern forests. Often destroying the forests on large areas in catastrophic burns, these wildfires frequently created open, tree-free environments above 3,000 ft (914 m) that were suitable for the growth and development of wild huckleberries. Some of the resulting huckleberry fields were heavily used by Indians.

Indians apparently dried their huckleberries by placing them near campfires or slowly burning rotten logs ignited for that purpose. Some years, when dry conditions and high winds were favorable, these drying fires may have spread and reburned the berry fields. The Indians also may have deliberately set fires to reburn the heavily used fields during dry, windy periods. In any event, periodic fires kept trees out of many huckleberry fields and created new fields where postfire environmental conditions were favorable for huckleberry growth.

Twelve blueberry-like huckleberry species grow in Oregon and Washington (Minore 1972), and huckleberry fields occupy over 100,000 acres (40 469 ha) in these two states.[1]/ Unfortunately, this acreage is dwindling. Most large wildfires have been effectively prevented or controlled in recent years, and Indian-set fires have not burned over the most heavily used, high-elevation, huckleberry fields for several generations. As a result, trees of low timber quality have been invading many high quality huckleberry fields (figs. 1 and 2). These trees eventually form dense subalpine forests that crowd and shade the shrubs, eventually eliminating huckleberry production.

Berry production is surprisingly high in some of the fields. We measured a yield of 100 gal per acre (935 l per ha) on one high quality huckleberry area in 1976. In 1977, when overall berry production tended to be poorer, another area produced 77 gal per acre (720 l per ha). Fresh huckleberries sold for $10.00-11.00 per gal ($2.64-2.90 per l) in 1977. Most berry pickers do not pick every berry on an area, but picking only half the berries would have produced economic yields of over $300 per acre ($741 per ha) on several areas sampled in 1977.

[1]Gerhart H. Nelson. Huckleberry management. 4 p. May 14, 1970. (Unpublished, on file at USDA Forest Service, Region 6, Portland, Oreg.)

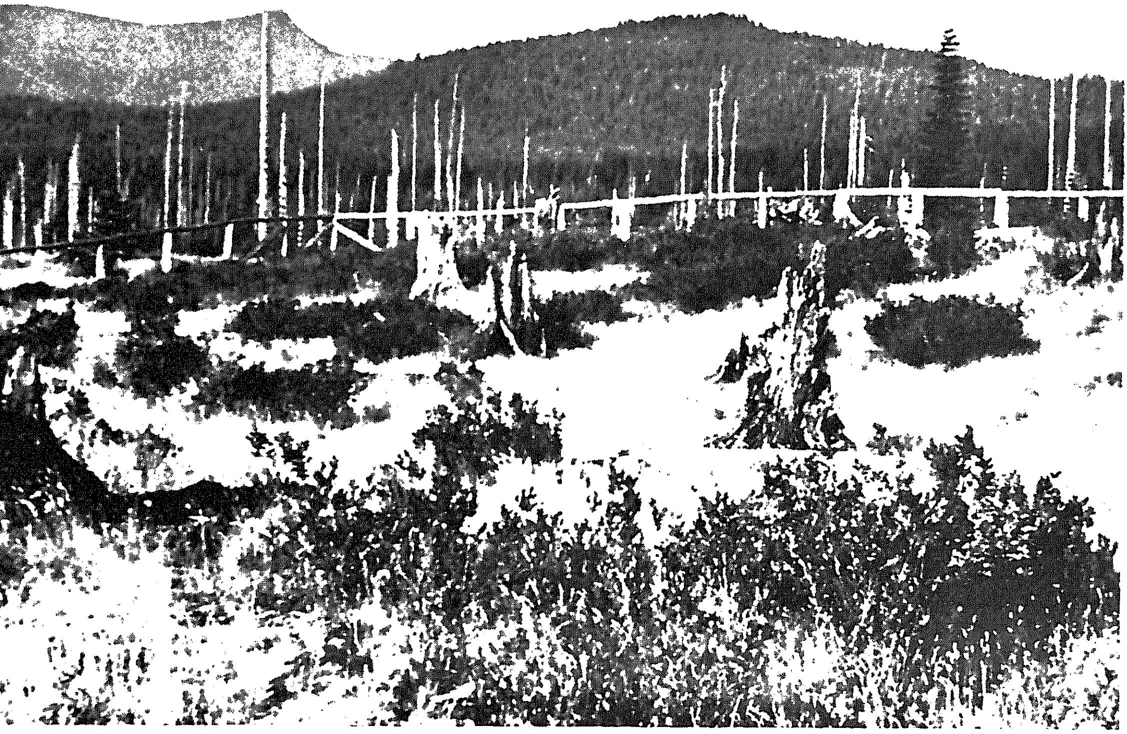


Figure 1.--A portion of the Sawtooth huckleberry field near Mount Adams, Washington in 1938. Note snags and open aspect.

Figure 2.--The same area shown in figure 1, 34 years later. These two photographs, taken at the same point, illustrate the rapid invasion by trees of this highly productive huckleberry field. Subalpine forest will soon reduce berry production.

Economic yields do not ade-
ately reflect the importance of
e northwestern huckleberry
source, however, for the in-
ngible values of fresh air,
untain scenery, and berry buckets
ey have filled themselves are far
re important than market values
most huckleberry pickers. Many
ople pick berries just for fun.
er a thousand vehicles were
llied in one ranger district's
rry fields during a single
ckleberry-season weekend in 1971.
another district, 163,000
sitor-days were recorded in one
avily used field during 1969 (see
otnote 1).

Considered either economically
recreationally, deterioration of
e northwestern huckleberry
source is serious. Several
ctors are involved: natural
ccession in the absence of
ldfires; huckleberry regener-
ion, growth, and berry produc-
on; meteorological effects; and
e regeneration, growth, and
mpetition of associated species.
eking a better understanding of
ese factors, we studied huckle-
rries from 1972 through 1977.
eld phenomena were investigated
two areas near Mount Adams,
shington, and Mount Hood, Oregon.
conducted laboratory and green-
use studies at the USDA Forestry
iences Laboratory in Corvallis,
egon. This report is a summary
the research at all three
cations during the 6-year study.

FIELD RESEARCH IN THE MOUNT ADAMS AREA

History

The huckleberry fields near Mount Adams have been heavily used by berry pickers for many years. Members of the expedition led by Captain George B. McClellan noted the extensive burned-over areas in this vicinity and found many Indians picking and drying berries there in 1853. One member recollected "a full tribe" and wrote "I never saw so many (Indians) and so many kinds of berries in all my life."[2]

Eighty-one years later, in 1934, an animal exclosure was constructed to monitor the effects of grazing in the berry fields. Vegetation within the exclosure and on an adjacent unfenced plot was observed yearly until 1942. The Forest Service observers concluded that sheep benefited the berries by reducing vegetative competition and lightly browsing the huckleberry shrubs.[3] In 1937, all trees were

[2] George Henry C. Hodges. Personal recollection. Page 146, Washington State Historical Society Publication. Volume 2, 1907 to 1914. (On file at USDA Forest Service Gifford Pinchot National Forest. Vancouver, Wash.)

[3] K. C. Langfield. Effect of grazing on huckleberry production. 2 p. December 9, 1942. (Unpublished, on file at Mount Adams Ranger District, Trout Lake, Wash.)

felled on 5 acres (2 ha) of berry field in the same Mount Adams area.[4] Later (1963), more trees were felled, and 6 acres were disked in an attempt to control vegetative competition.[5] Berry production was not measured on these felled or disked areas, but disking apparently stimulated rhizome sprouting. A huckleberry management plan was formulated for the Mount Adams huckleberry resource in 1968, but never implemented (see footnote 5).

Dr. Perry C. Crandall (Washington State University, personal communication, March 17, 1972) applied replicated herbicide treatments near Mount Adams in 1969. He found that Casaron, Simazine, Atrazine, and Paraquat were ineffective in selectively controlling vegetation competing with huckleberries. Crandall's huckleberry pruning trials (50 percent and 80 percent top removal) were also ineffective, damaging the huckleberry shrubs rather than improving them.

[4]George A. Bright. Huckleberry release from reproduction. 3 p. September 24, 1937. (Unpublished, on file at Mount Adams Ranger Station, Trout Lake, Wash.)

[5]Donald E. Wermlinger. Twin Buttes huckleberry management plan. 25 p. January 5, 1968. (Unpublished, on file at Mount Adams Ranger Station, Trout Lake, Wash.)

1972 Experiment

AREA DESCRIPTION

We established a vegetation control experiment 13 mi. (21 km) southwest of Mount Adams during the summer of 1972 in sec. 16, T. 7 N., R. 8 E. Located in a portion of the Sawtooth Huckleberry Field already invaded by subalpine forest, this experimental area is at an elevation of 4,000 ft. (1 219 m), with a gently sloping WSW aspect. Lodgepole pine, western white pine, subalpine fir, Douglas-fir, mountain hemlock, and Engelmann spruce comprise most of the forest canopy (see table 1, fig. 3).[6]

The 1972 experimental area occupies soil that is shallow, coarse-textured, gravelly, low in nutrients (table 2), and subject to erosion. Invading trees are short and poorly formed, often showing considerable snow damage. Snow packs usually are deep and long-lasting, and the growing season is cool and short.

[6]Table 1 lists scientific names for all plants mentioned in this report.

ble 1--Names of plants[1/]

Common name	Scientific name
oseris , orange	*Agoseris aurantiaca* Greene
adlily, Queencup	*Clintonia uniflora* (Schult.) Kunth
argrass	*Xerophyllum tenax* (Pursh) Nutt.
ueberry, eastern lowbush	*Vaccinium angustifolium* Ait.
amble, dwarf	*Rubus lasiococcus* Gray
nchberry	*Cornus canadensis* L.
nquefoil, Drummond	*Potentilla drummondii* Lehm.
uglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
erlasting, pearly	*Anaphalis margaritacea* (L.) B. & H.
scue, sheep	*Festuca ovina* L.
scue, western	*F. occidentalis* Walt.
r, grand	*Abies grandis* (Dougl.) Lindl.
r, noble	*A. procera* Rehder
r, Pacific silver	*A. amabilis* (Dougl.) Forbes
r, subalpine	*A. lasiocarpa* (Hook.) Nutt.
reweed	*Epilobium angustifolium* L.
wkweed, white	*Hieracium albiflorum* Hook.
mlock, mountain	*Tsuga mertensiana* (Bong.) Carr.
mlock, western	*T. heterophylla* (Raf.) Sarg.
ckleberry, big	*Vaccinium membranaceum* Dougl. ex Hook.
ckleberry, blue	*V. globulare* Rydb.
ckleberry, blueleaf	*V. deliciosum* Piper
ckleberry, evergreen	*V. ovatum* Pursh
ckleberry, red	*V. parvifolium* Smith
pine	*Lupinus* spp.
untain-ash	*Sorbus* spp.
tgrass, timber	*Danthonia intermedia* Vasey
lox, pink annual	*Microsteris gracilis* (Hook.) Greene
ne, lodgepole	*Pinus contorta* Dougl. ex Loud.
ne, western white	*P. monticola* Dougl. ex D. Don
ssytoes, rose	*Antennaria rosea* Greene
dcedar, western	*Thuja plicata* Donn
dge	*Carex* spp.
rrel, sheep	*Rumex acetosella* L.
irea	*Spiraea* spp.
ruce, Engelmann	*Picea engelmannii* Parry ex Engelm.
rawberry, western wood	*Fragaria vesca* L.
olet	*Viola* spp.
ldrye, blue	*Elymus glaucus* Buckl.
llow	*Salix* spp.
llow-herb, alpine	*Epilobium alpinum* L.
llow-herb, small flowered	*E. minutum* Lindl. ex Hook.
odrush, field	*Luzula campestris* (L.) DC.

[1/] Nomenclature follows Fernald (1950), Garrison et al. (1976), d Hitchcock and Cronquist (1973). Some of the common names were tained from Peck (1961).

Figure 3.--A portion of the experimental area near Mount Adams before treatment. Note invading trees.

ble 2--Soil properties at the Mount Adams experimental area[1/]

Property	Depth (cm)[2/] 0-15	16-30	31-46
	5.6	5.6	5.8
tion exchange capacity (meq/100 g)	13.19	13.10	11.66
tal nitrogen (percent)	.11	.07	.05
osphorus (pm)	14.00	6.00	3.00
tassium (pm)	28.40	16.40	11.20
lcium (meq/100 g)	1.04	.70	.39
gnesium (meq/100 g)	.08	.07	.05
dium (meq/100 g)	.02	.02	.03
ron (pm)	.22	.22	.20
etate extractable iron (pm)	42.00	53.00	168.00

1/ Average values based upon analyses of 4 samples--1 for each of e randomly distributed control plots.

2/ To obtain depth in inches, multiply by 0.394.

OBJECTIVES

The primary objective of this 1972 experiment was the development of a method that could be used to control competing species without reducing huckleberry[7] growth or berry production. Ideally, such a method would increase berry production by creating a more favorable environment for the plants. Secondary objectives included a study of plant succession after disturbance and assessments of the effects of sheep grazing on huckleberry growth and berry production and on forest regeneration.

EXPERIMENTAL DESIGN

We used a completely random experimental design in 1972, with five treatments replicated four times. The following treatments were randomly assigned to a grid of 20 plots (fig. 4): sheep grazing; cut and burn; burn; borax application; and control (no treatment). Each plot is 120 ft (37 m) square, occupying an area of 1/3 acre (0.14 ha).

[7]Throughout this report, "huckleberry" refers to Vaccinium membranaceum. Names of other Vaccinium species mentioned are given in table 1.

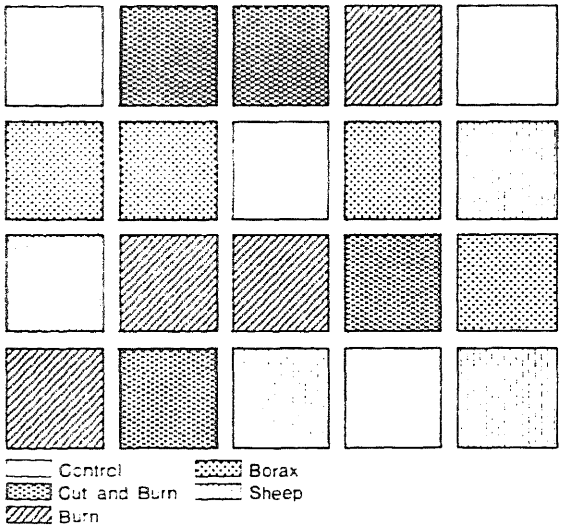


Figure 4.--1972 experimental plots near Mount Adams. Each 1/3-acre (0.14-ha) plot is 120 ft (37 m) square, with 10-ft (3-m) buffer strips between.

TREATMENTS

Sheep Grazing

We constructed a 3-ft (0.9-m) high woven wire fence around the entire experimental area and fenced all four sheep plots during July 1972. A cooperator provided 320 dry ewes. On August 22, eighty of these sheep were penned on each 1/3-acre (0.14-ha) sheep plot. They were confined on these small plots for 3 days, then returned to the cooperator. The resulting grazing intensity far exceeded anything that occurs during normal grazing operations, even exceeding the local intensity produced in bedding grounds. This deliberate

ergrazing was an attempt at
trolling competing vegetation,
it also served as a severe test
possible sheep damage to the
kleberry resource. (Many
kleberry pickers claim that
azing damages the huckleberries;
ey strongly oppose allowing sheep
the berry fields.)

t and Burn

All trees on the four cut-
d-burn plots were felled by chain
during the second week in
gust 1972; cut trees remained
ere they had fallen. Firelines
re constructed around each plot
ring the first week in September.

We attempted to burn during
second week in September. Drip
ches and slash fuel were used to
ite the 1-month-old slash, but
was not dry enough to burn. An
ly autumn storm covered the
erimental area with 4 in (10 cm)
snow on September 25. The snow
ted by September 29, however,
snowmelt was followed by
eral days of warm, dry weather
strong east winds. When
ning was attempted again October
o 7, a weather station 5 mi (8
) away, at the same elevation,
orded 2:00 p.m. relative humid-
es averaging 35 percent, average
imum temperatures of 66° F (19°
dry east winds averaging 7 mi/h
km/h), and 10 percent average
l moisture (10-h lag).[8] This time we used a flamethrower and about 150 gal (568 l) of diesel oil. Although the resulting fire would not spread through the slash, all of the plots were burned by applying the flamethrower over the entire area. Fine fuels, herbaceous vegetation, and huckleberry leaves were consumed by the oil-fueled flame. Coarse fuels, duff, and huckleberry stems were blackened, but not consumed (fig. 5).

Burn

Burning previously untreated plots was even more difficult than burning the slash on cut-and-burn plots; little fuel was present under the uncut trees, and a fire could not be kindled or spread. Nevertheless, by using about 150 gal (568 l) of diesel oil and the flamethrower, we burned all four plots from October 3 to 7. Huckleberry shrubs, herbaceous vegetation, and lower tree branches were burned deliberately. Burning intensity was slightly less than that obtained on the slash-covered plots. Fine fuels, herbaceous vegetation, and huckleberry leaves were consumed, but coarse fuels, duff, and huckleberry stems were only blackened (fig. 6). A few huckleberry stems survived.

[8]As measured with fuel moisture sticks, the
h lag represents the moisture content in
-1 in (0.6-2.5 cm) material.

Figure 5.--Cut-and-burn plot near Mount Adams, immediately after burn. October 1972.

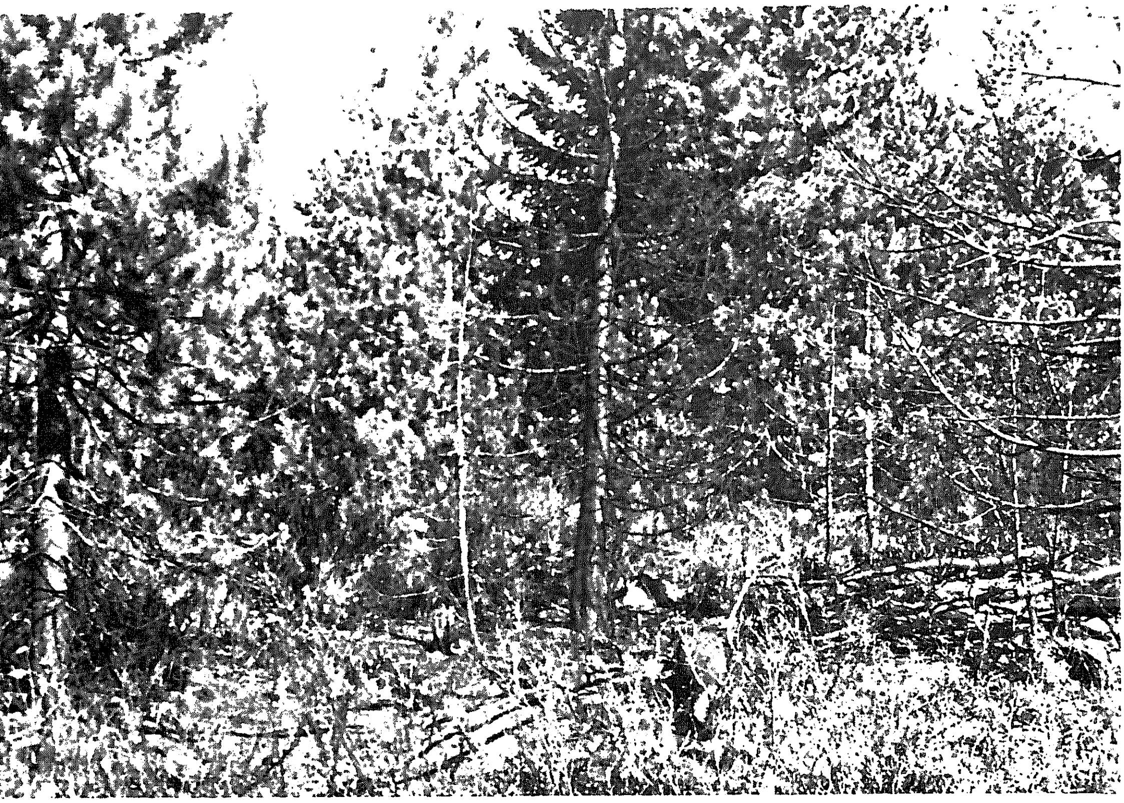


Figure 6.--Burn plot near Mount Adams, immediately after burning in October 1972.

orax Application

When borax was applied to astern lowbush blueberry fields at e rate of 1 or 2 lb per 100 ft^2 .5 or 9.8 kg per 100 m^2), it lled or injured several weedy ecies without injuring the berry ishes (Smith, Hodgdon, and Eggert 947). Although the eastern wbush blueberry is quite differ- t from our western huckleberry, we applied similar quantities of borax powder to four plots during the third week of September 1972. Dividing each plot into 49 equal areas, we scattered 5 lbs (2.27 kg) on each area--a total of 245 lb (111 kg) of borax per 1/3-acre (0.14-ha) plot. Borax is $Na_2B_4O_7 \cdot 10H_2O$, so the actual amount of boron applied was 27.8 lb (12.6 kg) per plot, or 83.3 lb/acre (93.4 kg/ha).

Control

All four control plots were inside the fence constructed to prevent indiscriminate grazing, but they received no other treatment.

DATA COLLECTION AND PROCESSING

Vegetation

We measured species composition and cover on all but the cut-and-burn plots in 1972, before treatment. (Cutting occurred before pretreatment vegetation could be measured on the cut-and-burn plots.) These measurements were repeated on all plots (including those cut and burned) in 1973, 1974, 1975, and 1977.

We used the line interception method described by Canfield (1941). Four 120-ft (37-m) lines were established at equal intervals on each plot. Measurements were taken along a tape stretched 3.3 ft (1 m) above the soil surface. Linear species coverage--first below and then above the tape--was recorded to the nearest 0.1 ft (3 cm) along the entire line each time. Thus, 480 ft (146 m) of line were measured on each of the 20 plots.

Except for grasses, linear measurements were converted to percentage cover for each plant genus. Linear grass measurements and total grass cover were recorded; grass species were identified, but separating percentage cover of individual grass genera and species proved to be impractical from the 1-m tape height. Dominance estimates were substituted for linear measurements of grass species. Sedges were recorded as *Carex* spp. Several other plant species were identified while blooming, but recorded as genera during cover measurements.

Berry Production

Huckleberry production was measured by picking and weighing the berries on 16 one-mil-acre (0.0004 ha) subplots in each treatment plot. These subplots were systematically located and permanently marked at equal intervals along the vegetation intercepts. The berries were picked in late August each year, combined on each plot, then weighed while fresh. All berries were picked and weighed on each of the 320 subplots (20 treatment plots) during 1972, 1973, 1974, 1975, and 1977. Random subsamples of ripe berries and of all berries harvested were then counted and weighed on each plot. The average weight of a ripe berry on that plot was then determined, as was the average weight of a harvested berry. (All berries, ripe and green, were harvested.) Harvested weight on each treatment plot was then converted to ripe weight by using the following equation:

$$\text{Ripe weight} = (\text{Harvested weight}) \times \left(\frac{\text{Average weight of a ripe berry}}{\text{Average weight of a harvested berry}}\right)$$

:tistical Analyses

Both vegetation and berry-
duction data were subjected to
lyses of variance each year.
verage of each plant species or
cies group and ripe berry weights
e compared among treatments in
se analyses. Where significant
ferences occurred, Scheffé (1959)
tiple comparison tests were used
identify the treatments.

RESULTS

Overstory Vegetation

As expected, the cut-and-burn treatment completely eliminated all overstory competition. Burning alone was less effective, but it also reduced the overstory cover. The burning killed many trees immediately. Others were severely injured and died several years later (fig. 7). By 1977, total

Figure 7.--The same burn plot shown in figure 6, 5 years after burning. August 1977.

overstory canopy on the burn plots was significantly 9/ less than that on the control, borax, or sheep plots (table 3). The sheep and borax treatments did not significantly affect overstory canopy composition or cover. Overstory canopy results are graphically compared in figure 8.

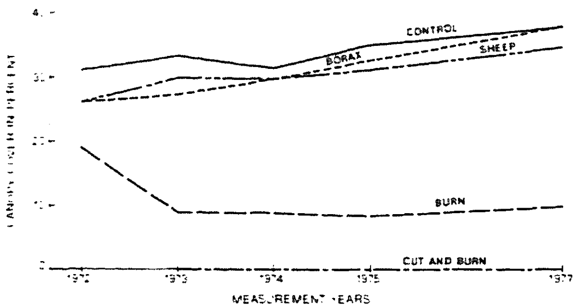


Figure 8.--Average overstory canopy at the Mount Adams experimental area. Treatments were applied between the 1972 and 1973 measurements.

9Unless otherwise noted in this report, significance refers to statistical significance at P< 0.05 as indicated by Scheffe tests.

Table 3—Average overstory cover (percent) on the Mount Adams experimental area[1]

Year and treatment	Lodge-pole pine	Western white pine	Douglas-fir	Sub-alpine fir[2]	Pacific silver fir[2]	Noble fir[2]	Engel-mann spruce[2]	Moun-tain hemlock	West-ern hemlock	Willow	Total overstory cover
1972 (before treatment):											
Control	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	32.1
Borax	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	[illegible]	26.1
Sheep	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	[illegible]	0	0.6	26.1
Burn	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	0	1.0	19.1
Cut and burn[3]	--	--	--	--	--	--	--	--	--	--	--
1973:											
Control	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	[illegible]	33.4
Borax	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	[illegible]	27.3
Sheep	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	[illegible]	0	1.7	29.9
Burn	[illegible]	[illegible]	[illegible]	0	0	0	[illegible]	[illegible]	0	0	9.2
Cut and burn	0	0	0	0	0	0	0	0	0	0	0
1974:											
Control	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0.5	31.5
Borax	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	[illegible]	29.8
Sheep	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]	0	1.3	29.6
Burn	[illegible]	0	0	0	0	0	[illegible]	[illegible]	0	0	8.9
Cut and burn	0	0	0	0	0	0	0	0	0	0	0
1975:											
Control	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0.2	35.0
Borax	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	0.1	32.7
Sheep	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	0	0.9	31.2
Burn	[illegible]	0	0	0	0	0	[illegible]	0	0	0	8.6
Cut and burn	0	0	0	0	0	0	0	0	0	0	0
1977:											
Control	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	1.3	0.6	37.7
Borax	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	0.1	37.8
Sheep	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0.9	34.8
Burn	[illegible]	[illegible]	0	0	0	0	[illegible]	[illegible]	0	0	4.8
Cut and burn	0	0	0	0	0	0	0	0	0	0	0

1 Each average represents four treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at P<0.05).

2 Absence on most treatment replications made statistical analyses impractical.

3 No vegetation data were collected on the cut-and-burn treatment plots in 1972.

derstory Vegetation

Burning significantly affected derstory cover and composition. ckleberry and beargrass cover rcentages initially dropped on e burned plots, then recovered. 1977, no significant differences curred among treatments for these o species (table 4). Understory ees did not recover as quickly, d the understory cover of lodge- le pine, western white pine, balpine fir, and Douglas-fir was wer on burned than on unburned ots in 1977.

Grasses were not significantly fected at first, but they began increase 2 years after being rned. By 1977 (5 years after eatment), grass cover was gnificantly greater on the burned ots than it was on unburned ots. Species composition was so affected. The dominant grass ecies on the burned plots in 1977 s timber oatgrass; dominant asses on the unburned plots were ue wildrye, western fescue, and eep fescue. Sedges, pearly erlasting, rose pussytoes, sheep rrel, and fireweed all responded ke the grasses--no significant fferences were recorded for 1 or years after burning, but by 1977 ey were significantly more undant on the burned plots. Few gnificant differences appeared ong burning treatments; burning th and without slash had similar fects on the understory. These fects are illustrated in figures and 9.

Understory vegetation on the control, sheep, and borax plots was not significantly affected by the 1972 treatments--with one exception. Pink annual phlox, a tiny herb, invaded the sheep plots 1 year after grazing to create a significantly greater cover there. By 1974 this seral species began to fade away on the sheep plots, and by 1977 it was found only where burning had occurred.

Berry Production

Both burning treatments significantly reduced huckleberry production on the Mount Adams experimental area (table 5). The huckleberry plants sprouted during the next growing season (fig. 10), but no flowers or berries were produced on these sprouts until 1975--3 years after the burning treatments were applied. Five years after treatment, a few berries occurred on the burned plots, but the bushes still had not completely recovered. Control plots produced 7 times as many berries as the burn plots and almost 300 times as many berries as the cut-and-burn plots in 1977. Although some of these 1977 differences in berry production were associated with differences in overstory protection from a severe local hailstorm, very few flowers or berries were present on the burned plots before or after the August storm.

Overgrazing by sheep reduced berry production for 2 years, but increased it during the 3d year after treatment. The borax treatment had little effect on berry production.

Table #4 which should appear on pages 17 & 18 will be found at back of book.

Figure 9.--The same cut-and-burn plot shown in figure 5, 5 years after burning (1977). Note grass cover and sprouting huckleberries.

le 5 --Average berry production on the Mount Adams experimental area[1]

reatment	Berry production by year				
	1972[2]	1973[3]	1974	1975	1977[5]
	Kilograms per hectare[4]				
trol	99.30	0	132.15	137.53	35.06
ax	61.43	0	43.22	69.07	44.98
ep	81.24	0	38.03	167.03	41.00
n	83.01	0	0.03	1.81	4.90
and burn	--	0	0	0.27	0.15

1/ Each average represents 4 treatment plots. Averages within a mon bracket are not significantly different (Scheffé tests were not nificant at P<0.05).

2/ Berries were picked before the treatments were applied. No producn data were collected on the cut-and-burn treatment plots.

3/ Unusual cold and very little snow during the 1972-73 winter, lowed by severe spring frosts, destroyed the 1973 berry crop.

4/ To obtain pounds per acre, multiply by 0.8922.

5/ A severe August hailstorm destroyed most of the berries on the erimental area.

Figure 10.--Sprouting huckleberry shrub on a Mount Adams cut-and-burn plot, 1 year after treatment. Note old shoots killed by the fire. August 1973.

iscellaneous Treatment Effects

Although the borax treatment roduced no statistically signifiant differences in overstory over, understory cover, or berry roduction, it did affect vegeation. Conifer needles developed rown tips during the spring of 973. In the fall, the new foliage n subalpine firs treated with orax was blue-green and seemed nusually vigorous. Beargrass lants were damanged slightly by ne borax; they developed abnormal nflorescences and produced few eeds in 1973. Furthermore, verage beargrass cover on the orax plots declined after treatent. It equaled the control cover efore treatment in 1972, but was ess than 60 percent of control over in 1977 (table 4). Unlike he sudden decline and subsequent ecovery after burning of bearrass, its slow decline on borax lots seems to be continuing.

Intensive overgrazing by sheep n 1972 did not significantly ffect the cover of forest tree pecies. It did significantly educe the number and average rowth of tree seedlings on the heep plots (table 6). Terminal ud nipping and trampling by the rowded, confined sheep seem to ave been responsible. The sheep lso added an estimated 2,000 lb of anure/acre (367 kg/ha) to the vergrazed plots.

Combustion of flamethrower oil probably was not complete when the burn and cut-and-burn plots were treated in 1972. Some contamination of the soil probably occurred from the 300 gal (1 136 l) of diesel oil used in burning the 2.7 acres (1.1 ha) occupied by these plots.

CONCLUSIONS

None of the four treatments successfully controlled competing species without damaging the huckleberries. Those treatments that controlled the competition (burning, cutting and burning) also reduced huckleberry production. Those that did not damage huckleberry (borax, sheep grazing) did not control competing species.

Sheep grazing did not damage the huckleberries. Although some browsing of the berry bushes occurred, this mechanical influence was more than offset by the nitrogen added as sheep manure. The damage to conifer seedlings (table 6) that resulted from overgrazing the sheep plots probably would be less severe under normal grazing practices.

Table 6 --Average tree seedling density and growth on sheep and control plots at the Mount Adams experimental area[1/]

Species	Seedlings per ha[2/] in 1976		Avg 1973 growth		Avg 1975 growth	
	Sheep plots	Control plots	Sheep plots	Control plots	Sheep plots	Control plots
	Number		Centimeters[3/]			
Lodgepole pine	5,752	12,046	4.9	7.2	6.0	6.3
Western white pine	2,179	2,832	4.9	8.2	4.8	6.5
Subalpine fir	1,905	2,090	3.3	5.1	4.1	4.8
Pacific silver fir	0	1,529	--	3.5	--	3.5
Grand fir	46	139	0	3.0	3.0	4.3
Noble fir	0	46	--	4.0	--	15.0
Douglas-fir	324	1,158	6.4	5.4	7.7	6.0
Mountain hemlock	46	185	2.0	7.2	6.0	11.2
Englemann spruce	139	46	1.3	12.0	1.3	16.0
All species	10,391	20,071	4.6	6.7	5.4	6.0

1/ Based on sixteen 12.5 m^2 (134.6 ft^2) circular samples systematically located on each of the 8 plots (4 sheep plots and 4 control plots). Significant ($P<0.05$) differences are underlined.

2/ To obtain seedlings per acre, multiply by 0.405.

3/ To obtain growth in inches, multiply by 0.394.

Recovery of the huckleberry ushes after fire seemed to be slow nd several competing species ppeared to recover faster. urning was difficult and large uantities of diesel oil were pplied, which may have influenced ur results. These results should e compared with those obtained in imilar burning experiments. urning eastern lowbush blueberry Black 1963, Smith and Hilton 1971) s not comparable, however, for the orphology and physiology of this astern species are very different rom the morphology and physiology f big huckleberry. Differences lso occur among the western *accinium* species, so conclusions bout *V. membranaceum* should be ased on *V. membranaceum* experi-ents.

Additional Mount Adams Field Research

Although our primary emphasis was on control of competing vegetation in the Mount Adams area, several other aspects of the huckleberry problem were investigated in smaller, previously published field studies. When the rhizome system and root structure of big huckleberry were investigated by hydraulic excavation (Minore 1975b), numerous robust rhizomes were found 8-30 cm (3-12 in) below the soil surface. The soluble solid contents of shaded and exposed huckleberry fruits sampled throughout one berry-picking season showed no significant exposure differences, but the berries were sweetest after beargrass began shedding seeds (Minore and Smart 1975). Finally, high huckleberry abundance was related to an optimum soil pH of 5.5 and the presence of seven associated plant species in a study of huckleberry environments (Minore and Dubrasich 1978).

FIELD RESEARCH IN THE MOUNT HOOD AREA

Area Description

Seven miles (11 km) southwest of Mount Hood, at an elevation of 4,800 feet (1 463 m), we established three field experiments in a uniform area where competing species are inhibiting huckleberry production. All three are in SE1/4, NW1/4 sec. 10, T. 4 S, R. 8 E.; and all are on gently sloping western aspects. A dense young conifer forest now occupies the site (fig. 11), but vegetatively vigorous huckleberry shrubs persist in the understory without producing many berries. Average overstory composition is 86 percent lodgepole pine, 7 percent noble fir, 4 percent Douglas-fir, 2 percent mountain hemlock, and 1 percent composed of scattered western white pine, subalpine fir, grand fir, western hemlock, Engelmann spruce, and western redcedar.

Figure 11.--Dense young conifer forest at the Mount Hood experimental area. There are 5,800 trees per acre (14,332 trees per ha) in the stand (55% are taller than 4.5 ft (1.4 m), 45% are seedlings). Big huckleberry is abundant in the understory, but berry production is poor.

Although its elevation is
eater, the Mount Hood experi-
ntal area is warmer than the
unt Adams area during summer.
nter snow packs remain there
nger than at Mount Admas, how-
er, and huckleberry development
ud burst, blooming, berry ripen-
g) is later at Mount Hood. On
ly 9, 1974, we had to use a
boggan to transport equipment over
mi (3.2 km) of snow-covered road,
d 3 ft (0.9 m) of snow still
vered portions of the access road
July 23.

Soil in the Mount Hood experi-
ntal area is shallow and rocky,
t less subject to erosion than
e soil encountered in the 1972
unt Adams experiment. Like the
unt Adams soil, it is low in
trients (table 7). Nevertheless, analyses of variance indicated that cation exchange capacity and contents of potassium, sodium, and boron are significantly higher in the Mount Hood soil than in the Mount Adams soil. Phosphorus and acetate-extractable iron are lower.

Bulldoze-And-Burn Experiment

OBJECTIVES

To test the effectiveness of mechanized overstory removal and subsequent slash burning for control of competing vegetation in the huckleberry fields, we conducted a bulldoze-and-burn to answer several questions: Does bulldozing provide suitable slash fuel for burning upper elevation huckleberry fields? If so, does it provide this fuel at less cost than tree-cutting with chain saws? Does the bulldoze-and-burn treatment seriously reduce huckleberry growth or berry production?

Table 7--Soil properties at the Mount Hood experimental area[1]

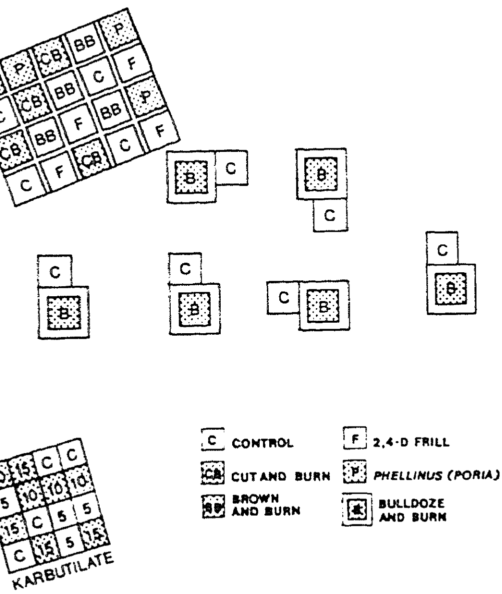
Property	Depth in centimeters[2]		
	0-15	16-30	31-46
pH	5.30	5.70	5.50
Cation exchange capacity (meq/100 g)	23.39	20.00	26.10
Total nitrogen (percent)	0.16	0.11	0.08
Phosphorus (pm)	4.90	6.00	6.40
Potassium (pm)	75.00	90.00	114.00
Calcium (meq/100 g)	0.69	0.29	0.38
Magnesium (meq/100 g)	0.12	0.07	0.07
Sodium (meq/100 g)	0.13	0.16	0.16
Boron (pm)	0.32	0.30	0.28
Acetate extractable iron (pm)	47.10	18.70	25.90

1/ Average values based upon analyses of 4 samples--1 for each of the randomly distributed control plots.

2/ To obtain depth in inches, multiply by 0.394.

EXPERIMENTAL DESIGN

We treated one plot in each of x pairs; the other, randomly eated plot was used an an un- eated control (fig. 12). Control ots are 1/3 acre (0.14 ha); jacent treated plots are the same ze, with an additional 30-ft (9- buffer strip that includes a actor-built fireline.



gure 12.--The Mount Hood experi- mental area showing the paired- plot bulldoze-and-burn experi- ment (center), the Karbutilate plots (lower left), and the grid plots (upper left). Kar- butilate plot numbers indi- cate pounds of active ingredi- ent per acre.

TREATMENT

A Caterpillar D6C tractor with 12-ft angle blade was used to push over all trees on each of the six treated plots on October 23 and 24, 1973. Trees larger than 14 in (36 cm) d.b.h. were difficult to uproot or break off. Those smaller than 4 in (10 cm) d.b.h. tended to spring back after the blade went over them. Except where buried by slash or disturbed by uprooted trees, huckleberry shrubs were not damaged by the tractor. After transportation charges were deducted, the bulldozing cost $34 per acre ($84 per ha).

Slash created by the bulldozing was burned the following summer, early in the evening on August 26, 1974. Eight miles (13 km) away and 350 ft (107 m) lower, a weather station recorded a 2:00 p.m. relative humidity of 23 percent, a maximum temperature of 84° F (29° C), northwest winds of 6 mi/h (10 km/h), and a 10-h lag fuel moisture of 7 percent (see footnote 8) for that date. Cooperating personnel from the Zig Zag Ranger District, Mount Hood National Forest, used drip torches to ignite each plot. No contamination with fuel oil occurred. The slash burned well, but the fire did not spread into areas without slash. Small patches (less than 10 percent of the area treated) remained unburned. Most huckleberry shoots were blackened, but not consumed.

DATA COLLECTION AND PROCESSING

Vegetation data were collected ı each bulldoze-and-burn plot in ɔ75 and 1977 by the techniques sed at Mount Adams. Huckleberry ıd total overstory cover were ıllied along four 120-ft (37-m) ınes established on each plot. ɔmpeting understory species were ɔt tallied.

Sixteen 1-milacre (0.0004 ha) ıbplots were established at equal ıtervals on each plot. Equal ımbers of these subplots were ındomly chosen on each plot in ɔ75 and 1977, and the berries on ıe chosen subplots were picked and eighed. Picked weights were ɔnverted to ripe weights by using ıe procedure described earlier.

Ripe berry weights, huckle-ɛrry cover, and total overstory ınopy cover on the treated and ɔntrol plots were compared by ıalyses of variance in 1975 and ɔ77.

RESULTS

The bulldoze-and-burn treat-ɛnt eliminated dense overstory ɔmpetition. The huckleberry ıderstory was severely damaged by ıe burn, however, and huckleberry ɔver and berry production had not ɛcovered to control levels 3 years ˈter treatment (table 8). Huckle-ɛrry shrubs sprouted vigorously ˈig. 13), but they produced very ɛw berries.

CONCLUSIONS

Bulldozing provided suitable slash fuel for burning upper elevation huckleberry fields if the slash was allowed to dry for 1 year. It provided this fuel at less cost than tree-cutting with chain saws. The bulldoze-and-burn treatment effectively eliminated competing vegetation, but burning the slash seriously damaged huckleberry shrubs and reduced berry production for at least 3 years. Bulldozed sites look unattractive; bulldozing should not be done in scenic areas or where soil erosion is a problem.

Karbutilate Experiment

OBJECTIVE

Researchers in the Coast Ranges of Oregon and Washington observed that karbutilate killed most plant species, but had little effect on evergreen huckleberry and red huckleberry. Our objective was to determine if it could be used to kill competing plant species in Cascade Range huckleberry fields without affecting big huckleberry.

EXPERIMENTAL DESIGN

Four treatments were replicated four times in a completely random experiment. One-tenth-acre (0.04 ha) plots were used in a four-by-four grid (fig. 12). The following treatments were randomly assigned to these plots: 5 lb karbutilate/acre (5.6 kg/ha); 10 lb karbutilate/acre (11.2 kg/ha); 15 lb karbutilate/acre (16.8 kg/ha); and control (no treatment).

le 8--Average overstory cover, huckleberry cover, and berry production on the Mount Hood bulldoze-and-burn experimental plots[1]

	1975		1977	
	Control plots	Bulldoze-and-burn plots	Control plots	Bulldoze-and-burn plots
rstory cover percent)	45.30	0.20	50.60	0.20
kleberry over (percent)	33.00	6.00	35.20	9.40
ry production kg per ha)[2]	94.85	10.14	66.73	7.89

[1] All control vs. bulldoze-and-burn differences are statistically nificant ($P<0.05$).

[2] To obtain pounds per acre, multiply by 0.8927.

igure 13.--Three-year-old huckleberry shoots on a bulldoze-and-burn plot near Mount Hood. They are not producing berries.

TREATMENTS

The active ingredient in ndex[10]/ is karbutilate (*m*-(3,3-methylureido) phenyl *tert*-tylcarbamate). It is often used a soil sterilant. Mammalian xicity is very low. We applied a anular form of the chemical andex 10 G) in late June 1975, by iformly spreading measured ounts on treated plots as the st snow was melting. We were tremely careful to secure an even stribution of the chemical and pended about 8 man-hours per acre 0 man-hours per ha). Control ots were located and marked, but ey received no other treatment.

DATA COLLECTION AND PROCESSING

Overstory and understory cover re recorded in both 1976 and 1977 ong three lines established on ch of the 16 plots. As in the her huckleberry experiments, the sulting linear measurements were nverted to percentage cover for ch species. Cover percentages re then subjected to analyses of riance. Where significant fferences occurred, Scheffé ltiple comparison tests were used identify the treatments in-lved. Berry production was served, but not measured on the eated plots.

[10]Mention of companies or products does not nstitute an endorsement by the U.S. Department Agriculture.

RESULTS

The karbutilate applications produced no immediate results, but huckleberry leaves began to turn brown 1 month later. By late autumn 1975, a few of the overstory trees also began to show herbicide damage. One year later, effects of the herbicide were evident (fig. 14). The two heaviest applications

Figure 14.--A karbutilate plot 15 months after treatment with 15 lb of karbutilate per acre (16.8 kg/ha). The trees and huckleberry shoots are dead. September 1976.

Table 9—Average vegetative cover in percent on plots treated with karbutilate[1]

and treatment	Overstory[2]				Understory[2]						
	Lodgepole pine	Douglas fir	Noble fir	All species	Big huckleberry	Beargrass	Dwarf bramble	Pearly everlasting	Violet	Lodgepole pine	Total huckleberry competition
:											
Control	53.5	3.6	2.6	61.1	22.6	10.5	4.7	1.9	0.4	1.6	24.0
lb/acre (5.6 kg/ha)	34.6	7.2	1.9	46.1	9.8	8.1	4.3	0.7	0.9	1.0	18.8
lb/acre (11.2 kg/ha)	7.3	4.4	1.4	12.0	2.1	8.0	2.4	0.1	0.2	0.6	11.9
lb/acre (16.8 kg/ha)	3.9	3.6	3.3	9.0	2.4	9.5	1.0	0.1	0.4	1.5	13.0
:											
Control	49.4	4.0	2.9	58.4	30.2	7.6	6.6	2.2	0.5	3.3	23.6
lbs/acre (5.6 kg/ha)	28.8	5.6	3.5	38.5	22.5	5.7	4.9	0.8	1.0	1.4	17.8
lb/acre (11.2 kg/ha)	2.3	5.6	0	3.6	8.7	7.5	5.3	0.3	0.4	0.7	15.8
lb/acre (16.8 kg/ha)	1.5	3.9	0.2	5.6	5.1	8.6	2.7	0.1	0.9	0.2	13.5

1/ Each average represents 4 treatment plots. Averages within a common bracket are not significantly different (Scheffé tests e not significant at P<0.05).

2/ Only major species are listed individually, but all are included in the "all species" and "total huckleberry competition" umns.

uld be identified on the ground amount of vegetation damaged. deed, most plants (including ckleberry shoots) were dead. The -lb/acre (5.6-kg/ha) treatment oduced significantly less damage able 9); many of the overstory ees and huckleberry shoots were t killed.

Lodgepole pine was damaged re than noble fir by the herbicide, d noble fir was damaged more than uglas-fir. We noted that karbuti- te killed all of the conifer species from the bottom up. (When affected by 2,4-D, they die from the top down). Huckleberry shrubs appear to be slowly recovering from the treatments. Some of the damaged shoots bear a few green leaves, and some rhizomes are sprouting. Nevertheless, treated plots produced few berries in 1977, and many brown, curled leaves or bare huckleberry branches remained.

CONCLUSIONS

Karbutilate nearly eliminated peting vegetation in a huckle-ry field when applied at 10-15 acre (11.2-16.8 kg/ha). Un-tunately, it also nearly elimi-ed huckleberry. Lesser quantities karbutilate were less effective reducing competition and less aging to huckleberry.

e-Treatment Grid

OBJECTIVE

Like the 1972 experiment at nt Adams, this Mount Hood eriment had as its objective the elopment of a method of con-lling vegetation that could be d against competing species hout reducing huckleberry growth berry production. A successful hod should increase berry duction.

EXPERIMENTAL DESIGN

We duplicated the completely dom experimental design used in 1972 experiment at Mount Adams this five-treatment, four lication grid, but applied ferent treatments (fig. 12): and burn; brown and burn; 2,4-D ll; *phellinus (Poria)* inocu-ion; and control (no treatment). at Mount Adams, each grid plot 120-ft (37-m) square, occupying area of 1/3 acre (0.14 ha).

TREATMENTS

Cut and Burn

With chain saws, we cut all of the overstory trees on the four cut-and-burn plots in September 1973. The operation required about 18 man-hours per acre (44 man-hours per ha). The resulting slash was left in place, and firelines were built around each plot.

The 11-month-old slash was burned by Zig Zag Ranger District personnel late in the afternoon on August 26, 1974. Meteorological conditions for that date are recorded elsewhere (see bulldoze-and-burn experiment). Relative humidity was 30 percent and the temperature was 76° F (24° C) when burning commenced 4:00 p.m. Although the slash burned readily after being ignited with drip torches, several small areas without slash (less than 10 percent of the area treated) did not burn at all. Most huckleberry shoots were blackened, but not consumed by the fire.

Brown and Burn

Firelines were constructed around the four brown-and-burn plots in October 1973. These plots were treated with a low volatile ester of 2,4-D on July 23, 24, 25, and 26, 1974. We mixed three lb (1.36 kg) 2,4-D with 3 gal (11.4 l) of diesel oil and 97 gal (367.2 l) of water, then sprayed the resulting emulsion

ll vegetation. The vege-
ion was dense, and we used about gal of emulsion per acre (1 777 a). Most of the foliage below t (3 m) turned brown during following month.

Burning was attempted at the e time that adjacent cut-and- n plots were successfully ited, but here it failed. Dry eline slash along the plot edges ned, but the other vegetation-- n the brown pine needles and bicide-damaged huckleberry ubs--would not carry a fire. s, the brown-and-burn treatment browned, but not burned. It ame a test of broadcast spraying n low volatile 2,4-D ester.

-D Frill

A one-to-one mixture of 2,4-D ne and water was applied to ividual trees on the 2,4-D frill ts. We used a hatchet to cut lls 1.5 in (3.8 cm) apart around ry tree larger than 2 in (5 cm) h. and squirted the 2,4-D ution into the frills with a stic squeeze bottle (fig. 15). s operation is sometimes re- red to as the "hack-squirt" hnique. Frill plots were ted on July 8-11, 1974, when nants of the heavy winter snow t remained as drifts and huckle- ry shrubs were just beginning to duce leaves. The large number overstory trees (3,200/acre or 00/ha) made this treatment very e consuming. It required about man-hours/acre (52 man-hours/ha).

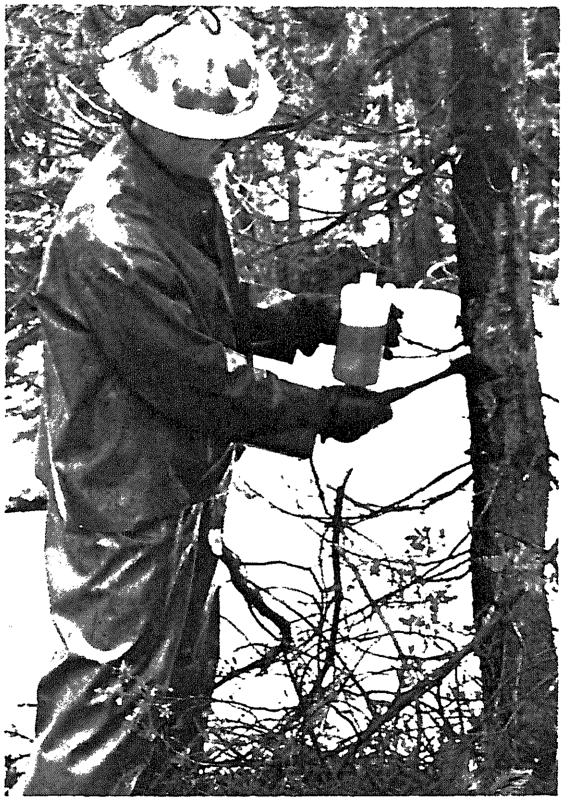


Figure 15.--2,4-D amine being applied to frills cut in an overstory tree. Note hatchet, squeeze bottle, and snowdrift in background. July 1974.

Phellinus (*Poria*) Inoculation

Phellinus weirii (Murr.) Gilbertson (a native, root-rotting fungus that attacks conifers) spreads slowly, but remains in the soil for long periods after it becomes established. Establishment by inoculation could result in continuous, long-term overstory thinning in the huckleberry fields.

hologists Earl E. Nelson[11] and en W. Todd[12] inoculated 25 l-spaced trees on each of the r *Phellinus* plots. At each e, two lateral roots were avated and scarred by removing a ip of phloem and cambium. *llinus weirii* inoculum (alder-ck cultures) was then placed in tact with the exposed root em, wrapped in plastic, and ied. Tree species and diameter, t size, root direction, and the culation point on each root were orded. Azimuths and distances ween inoculated trees on each t were also recorded, and the culated trees were labeled with al tags.

trol

Four control plots were ated and permanently marked in field. No treatments were lied, and the control plots were isturbed except for periodic surements of vegetation and ry production.

DATA COLLECTION AND PROCESSING

Vegetation data were collected 1975 and 1977 on the five-atment grid by methods used in bulldoze-and-burn experiment. y huckleberry cover was recorded ow the four 120-ft (36.6-m) es established on each of the 20 ts. Overstory cover was re-ded by species on the grid

[1]USDA Forestry Sciences Laboratory. vallis, Oregon.

[2]Oregon State University, Corvallis, Oregon.

plots, however, and both total overstory and overstory cover by species were obtained.

Berry production was measured in 1975 and 1977 by picking and weighing all the berries on 16 systematically spaced 1-milacre (0.0004-ha) subplots on each of the 20 plots. Picked weights were converted to ripe weights by using the procedure described on page 13.

Ripe berry weights, huckleberry cover, and overstory cover were subjected to analyses of variance in 1975 and 1977.

RESULTS

Overstory Vegetation

Overstory vegetation was significantly reduced by the herbicide spray in the brown-and-burn treatment, which affected lodgepole pine more than the other tree species (table 10). The 2,4-D frill treatment was much more effective, however; it killed all but 8.7 percent of the overstory cover (fig. 16). Only the frilled trees were affected by 2,4-D. *Phellinus weirii* inoculations showed no visible results in 1977, and *Phellinus* plot overstories did not differ significantly from the controls (fig. 17).

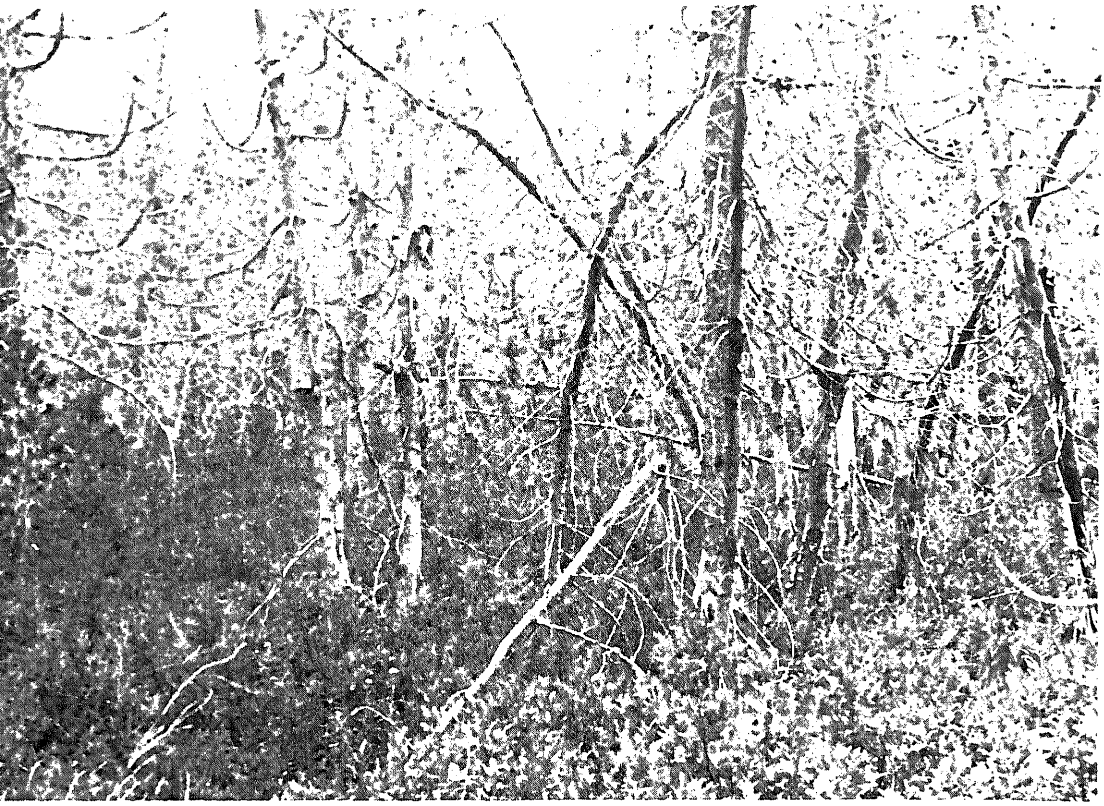
Table 10—Average berry production, huckleberry cover, and overstory cover on the Mount Hood 5-treatment plot grid[1]

Year and treatment	Berry production	Huckleberry cover	OVERSTORY COVER										
			Lodge-pole pine	Noble fir	Douglas-fir	Moun-tain hemlock	Sub-alpine fir	Engel-mann spruce	Western white pine	Grand fir	Western hemlock	Western redcedar	Total all species
	kg/ha[2]	- - - - -	- - - - -	- - - - -	- - - - -	- - Percent - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -
1975:													
2,4-D frill	72.43	46.1	2.0	4.3	1.5	0.7	0	0	0	0	0	0	8.5
Phellinus	173.94	42.9	41.3	4.6	5.3	0.7	2.4	0	0.5	0	0	0	54.8
Control	107.14	44.0	46.0	3.7	1.7	0.8	0	0	0.2	0.5	0.1	0	53.0
Brown and burn	0	5.9	22.4	3.1	4.3	1.5	0	2.1	0.1	0	0.2	0	33.7
Cut and burn	2.70	7.1	0	0	0	0	0	0	0	0	0	0	0
1977:													
2,4-D frill	192.90	49.1	3.1	2.8	1.8	0.9	0	0	0	0	0	0.1	8.7
Phellinus	105.56	45.0	43.9	5.4	5.9	0.9	0.7	0	0.8	0	0.2	0	57.8
Control	73.55	45.2	52.1	4.2	2.5	1.0	0	0	0.3	0.5	0.1	0	60.7
Brown and burn	16.18	28.0	28.3	3.9	5.8	2.0	0	0.6	0.1	0	0.4	0	41.1
Cut and burn	2.36	17.0	0	0	0	0	0	0	0	0	0	0	0

1/ Each average represents 4 treatment plots. Averages within a common bracket are not significantly different (Scheffé tests were not significant at P<0.05).

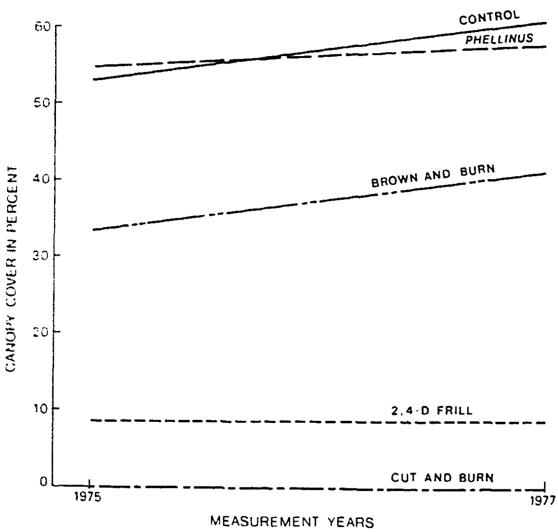
2/ To obtain pounds per acre, multiply by 0.8922.

3/ Absence on most treatment replications made statistical analyses impractical.



ure 16.--A 2,4-D frill plot 3 years after treatment. Note dead overstory
rees. Huckleberry shrubs comprise the understory. September 1977.

ure 17.--Average overstory canopy
n the Mount Hood grid plots.
reatments were applied in 1974.



Overstory species reacted ferently to the 2,4-D frill atment. Lodgepole pine was most ceptible, followed by noble fir, ch was more susceptible than glas-fir. Mountain hemlock was t resistant. All trees affected the 2,4-D frill treatment died n the top down, not (as in the butilate treatments) from the tom up.

kleberry Cover

Although burned shrubs sprouted orously, burning significantly iced the huckleberry cover sured on cut-and-burn plots in 5, 1 year after treatment. This iction was still significant ears after treatment, in 1977 ble 10). The brown-and-burn ts were never successfully ned, but they also experienced a nificant reduction in huckle-ry cover in 1975, a reduction sed by the 2,4-D spray used for wning. Herbicide damage seems have affected the huckleberry nts less severely than fire age, however, for by 1977 the rage huckleberry cover on brown--burn plots, though still much s than that of the controls, eared to be increasing faster n on the cut-and-burn plots.

Huckleberry cover on the 2,4-D ll, *Phellinus*, and control plots increased slightly from 1975 to 7. No significant differences irred among these three treat-ts.

Berry Production

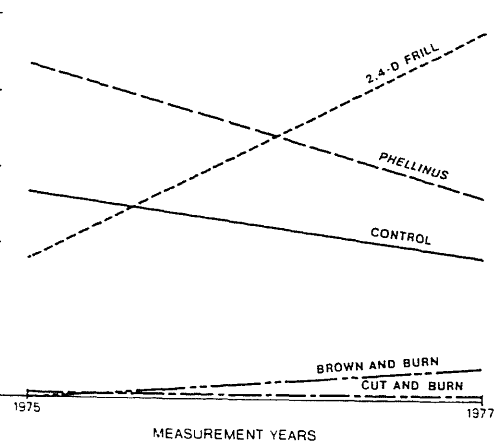
As it did in the Mount Adams experiment, the cut-and-burn treatment at Mount Hood essentially eliminated huckleberry production 1 year after treatment (table 10). The few berries picked in 1975 came from shrubs that were not burned. Three years after treatment, in 1977, berries were still limited to those few shrubs, and no increase in production occurred. Burned shrubs sprouted vigorously during the 1st year after treatment, but produced no berries 3 years after burning (fig. 18).

Berry production was also eliminated on the brown-and-burn plots 1 year after treatment. Huckleberries sprayed with 2,4-D bore a few berries again during following years, however, and in 1977 the brown-and-burn plots produced much more than the cut-and-burn plots (table 10). Nevertheless, berry production on brown-and-burn plots was far below the production attained on control, *Phellinus*, or 2,4-D frill plots.

Although berry production on the *Phellinus* plots was higher than that on control plots in both 1975 and 1977, the difference was not statistically significant in either year. Production was appreciably lower for both treatments in 1977 than it was in 1975 (table 10). *Phellinus weirii* inoculations did not affect berry production.

Figure 18.--Huckleberry shrub on a Mount Hood cut-and-burn plot, 3 years after burning. Note vigorous young shoots and absence of berries. September 1977.

Fewer berries were produced on 2,4-D frill plots than on the :rol plots in 1975, but the 'erence was not statistically ificant. Three years after tment, in 1977, the frill plots uced more than twice as many ies as the controls, and the 'erence was significant. hermore, although production ined on all other plots but e recovering from herbicide ying between 1975 and 1977, it eased during the same period on D frill plots (fig. 19). leberries were abundant on the led plots in 1977 (fig. 20).



gure 19.--Average berry production on the Mount Hood grid plots. Treatments were applied in 1974.

CONCLUSIONS

Although the Mount Hood experiment was not contaminated with diesel oil, the cut-and-burn treatment was no more successful there than it was near Mount Adams. Huckleberry shrubs burned in the summer or autumn sprout during the following summer, but do not produce berries for at least 3 years after the fire.

One-year-old slash carries fire satisfactorily, and flame-thrower burning is not necessary if this slash is burned during warm dry weather. Warm dry weather probably will not be sufficient for a satisfactory burn in high elevation huckleberry areas where dry slash is absent, however. Success in burning may require that it be done during high-hazard conditions, which are infrequent. Low fuel densities, frequent fogs, and heavy dews seem to be responsible for unsatisfactory burning. Herbicide browning of the foliage does not provide enough dry fuel to carry a fire on slash-free sites. *Phellinus wierii* inoculations might thin the overstory canopy without the need for either fire or slash, but *Phellinus* has had no visible effect on our plots. We can only conclude that benefits of inoculation, if any, will be slow in appearing.

igure 20.--Huckleberry shrub on a 2,4-D frill plot, 3 years after treat-ment. Note abundant berries. September 1977.

Application of 2,4-D amine in ills had little effect on berry oduction during the first year ter treatment, but it greatly duced the overstory canopy. This reduction in overstory canopy was accomplished without damaging the huckleberry understory. It created favorable conditions for berry production.

LABORATORY RESEARCH

Considerable time and effort e spent in culturing huckleberry laboratory growthchambers and enhouses. Our initial attempts e rooting trials. Two thousand m cuttings were collected from mant shoots in June 1972. These tings were placed in a peat-sand ture under intermittent mist. broke buds. None rooted. In e July, another 2,000 stem tings were collected from wing shoots. They were soaked an indolebutyric acid solution mg IBA/1 water) overnight, then sed before being placed in the t-sand mixture under inter- tent mist. Again, none of the m cuttings rooted. Rhizome tings grew vigorously, even when lected in midsummer and potted hout further treatment.

As our attempts to root stem tings failed, and as uniform nts are difficult to obtain from zome cuttings, we cultured *cinium* plants from seed. *V. branaceum, V. globulare,* and *V. iciosum* all grew equally well er the conditions described.

Ripe berries were pulped in a nder with water and a small unt of detergent added to wet seeds and prevent them from ating away with the pulp. The ulting slurry was placed in a h and decanted under a slow eam of water. The pulp floated y, leaving the seeds in the dish tom. These seeds were air- ed, then sown on moist peat kept at cool growthchamber temperatures (18° C or 64° F, 12-h days and 13° C or 55° F, 12-h nights were satisfactory). Seed stratification was not necessary, and germination occurred in 16-21 days.

The resulting seedlings grew rapidly when watered periodically with a nutrient solution based on the macronutrient proportions published by Ingestad (1973) and the micronutrients listed by Minton, Hagler, and Brightwell (1951):

Macronutrient Solution (in 1 liter H_2O)

0.048 g $NH_4H_2PO_4$

0.095 g KCl

0.041 g $Ca(NO_3)_2 \cdot 4H_2O$

0.086 g $MgSO_4 \cdot 7H_2O$

0.341 g NH_4Cl

Micronutrient Stock Solutions[13]

0.90 g manganese chloride/500 ml H_2O

0.10 g zinc sulfate/500 ml H_2O

0.05 g cupric sulfate/500 ml H_2O

0.50 g boric acid/500 ml H_2O

0.08 g molybdic acid/500 ml H_2O

19.23 g sequestrine NaFe/500 ml H_2O

[13] One ml of each stock solution was added to each liter of macronutrient solution.

Excellent growth occurred in chambers set for 20° C (68° F), 14-h days and 14° C (57° F), 10-h nights. When well watered, the plants also grew satisfactorily in greenhouse and lathhouse conditions.

When *V. membranaceum* plants were grown from seed, they first bloomed during their third growing season. Rhizomes were first formed during the third growing season (fig. 21). Rhizome formation in *V. deliciosum* apparently occurs much earlier--we found rhizomes on 1-year-old growthchamber seedlings.

Using *V. membranaceum* cultured from seed, we cooperated with an Oregon State University graduate student who studied the relation of nutrients and pH in a greenhouse and in the field (Nelson 1974). He found in both places that vegetative growth increased with added nitrogren. Better growth in the greenhouse occurred at pH 5.0 than at 3.0, 4.0, or 6.0. *V. membranaceum* seedlings were also used in a study of the comparative tolerances of huckleberry and lodgepole pine to boron and manganese (Minore 1975a).

Figure 21.--V. membranaceum *rhizome produced during the third growing season in a lathhouse. Our growth chamber, greenhouse, and lathhouse plants formed no rhizomes during their first two growing seasons.*

pine was more tolerant to on. We used seedlings of *V. branaceum, V. deliciosum,* and *globulare* in a carefully con- lled study of frost tolerance nore and Smart 1978). *V. iciosum* was significantly more st tolerant than the other cies.

Beargrass is a major com- itor in the huckleberry fields in high elevation clearcuttings, herbicides, burning, and zing have been ineffective in trolling it. Past attempts to ture beargrass have been ham- ed by the inability to germinate seeds. After trying several hods, we obtained successful (64 cent) germination by stratifying seeds for 16 weeks (Smart and ore 1977). The seedlings were cessfully cultured under the e nutrient, temperature, and toperiod regimes used in growing *membranaceum*.

DISCUSSION

Although we tested vegetation control methods in only two areas, these areas appear to be typical of the berryfields that occur at elevations of 4,000-6,000 ft (1 220-1 830 m) in the Cascade Range of Oregon and Washington. Lodgepole pine, western white pine, beargrass, lupines, and grasses are the most important huckleberry competitors in the areas studied. Burning the slash created by cutting or pushing over all trees with a tractor eliminated the lodgepole and white pine competition. Beargrass, lupines, and grasses, however, were not satisfactorily controlled. Indeed, grass growth was stimulated by burning.

Controlled burning is exceedingly difficult in northwestern huckleberry areas at these elevations. Without dry slash to carry the fire, burning appears impossible except during hazardous meteorological conditions; it seems counterproductive when short-term benefits are desired. Abundant berries did not occur after our fires. Although the huckleberry bushes sprouted almost immediately after being burned, the sprouts did not begin to bloom until the third growing season. Significant berry production was delayed for at least 5 years and perhaps much longer. Meanwhile, tree seedlings from adjacent unburned stands began to invade the burned area. Unless this area is very large (comparable to the areas burned by wildfires in former years), reinvasion of burned areas by trees may be almost as fast as huckleberry recovery.

Spring burning increased *V. bulare* stem density within 1 r in the larch/Douglas-fir ests of western Montana (Miller 7), but Montana results may not ly to huckleberry in Oregon and hington. Western Montana ironments differ from Pacific thwest environments. Furthermore, morphology and sprouting be- ior of *V. globulare* in Montana emble that documented for *V. ustifolium* (Miller 1978); be- ior of big huckleberry does not emble that of *V. angustifolium,* it probably also differs from t of *V. globulare*. *V. globulare,* e *V. angustifolium,* may recover m fire more rapidly than big kleberry.

Season of burning--not cies differences--probably was ponsible for higher stem density some of the Montana fire plots. sity-increasing burns there urred in the spring, when soil sture was higher and heat etration was shallower than in autumn. The Montana autumn ns, like our burning treatments, uced stem densities. As our nt Adams burning treatments were lied less than 2 weeks after an ly autumn snowfall, however, and the Mount Hood burning was done y 5 weeks after the disappearance a heavy winter snow pack, our ns may have occurred under soil sture conditions similar to se of a Montana spring. In any e, snow cover makes spring ning impossible in most north- tern huckleberry fields. Summer and autumn burning reduced both stem density and berry production for at least 5 years.

Sheep grazing--even severe overgrazing--did not damage the huckleberries. It may even have benefited them by adding nitrogen to the soil. Unfortunately, added nitrogen is of little value to huckleberries growing under a closed forest canopy, and sheep grazing does not eliminate this forest canopy or retard its closure.

Applications of karbutilate eliminated the forest canopy, but they also eliminated the huckle- berries growing under that canopy. The huckleberries could recover and sprout again, but the prospects are not encouraging. Boron applica- tions are even less encouraging and should not be considered further.

Successful *Phellinus weirii* inoculations probably would main- tain an open overstory indefi- nitely. As yet, the inoculations have not been successful, however, and we will have to wait several more years to see if this form of biological control merits further investigation.

Application of 2,4-D amine to frills cut in each treated tree certainly deserves further investigation. The method is expensive in dense stands like those treated near Mount Hood, but it would be an economical way to eliminate trees at earlier seral stages when stand

sity is much lower. We
nd no evidence of the 2,4-D
ing out of treated trees.
lied in frills, the herbicide
eared to be safe as well as
icient.

Dense shade is detrimental to
kleberry production, and some
t of overstory control is needed
preserve and maintain existing
ry fields. Partial shade does
seem to be harmful, however,
the slight overstory protection
orded by dead snags or a thin
rstory canopy may even be
eficial. Absolutely open
ditions, without shade of any
d, may be less desirable than
s light partial shade.

Shrub disturbance is detri-
tal to production of huckle-
ries. Old shrubs continue to
duce berries year after year,
hout pruning or other rehabili-
ion. When these old shrubs are
ned, cut, or otherwise dis-
bed, they stop producing berries
start producing vigorous new
ots. Unfortunately, vigorous
shoots do not produce many
ries.

Vigorous new shoots should
duce many berries eventually,
ever. When they do, areas
t were disturbed by burning may
more productive than undisturbed
as. The long-term benefits of
ning might then exceed the
rt-term benefits obtained by
lying 2,4-D in frills. We will
tinue to monitor all of our
erimental plots to see if this
urs.

MANAGEMENT RECOMMENDATIONS

Huckleberry management will be expensive, and the areas to be managed should be carefully selected. Access, public use, and berry production should all be considered. In many areas, the public already is using easily accessible areas that are known to produce good berry crops. Preserving and maintaining these traditional picking grounds should be given highest priority. The following recommendations are applicable to huckleberry areas at 4,000-6,000 ft (1 220-1 830 m) in the Cascade Range of Oregon and Washington.

Overstory trees should be controlled in the areas to be managed. If berry production is to be maintained or increased without delays of 5 years or longer, this must be done with minimal disturbance of the huckleberry understory.

A one-to-one solution of 2,4-D amine and water, applied to frills cut in the individual trees, effectively kills a conifer overstory without disturbing the huckleberries. It should be applied in the spring, just as conifer buds are breaking. Where herbicide use is undesirable, individual tree girdling would produce the same result at somewhat higher cost. Frilling and girdling will be least expensive when done before a dense overstory canopy develops.

Where dense overstory canopies cupy large areas that are to be naged for huckleberries, and ere berry production delays of 5 ars or longer are acceptable, the lldoze-and-burn treatment should considered. Using a crawler-pe tractor with raised bulldozer ade, all trees in a large area ould be pushed over and allowed dry for a year before burning is tempted. Burning should then be ne while soil moisture remains gh, as soon as the slash will rry a fire. This method has a vere visual impact on the land-ape, it will eliminate berry oduction for several years, and ng-term berry production benefits e unknown. Nevertheless, it is ch cheaper than frilling or rdling where dense unmerchantable erstories are to be removed. ere merchantable overstories ist, conventional clearcutting obably would be just as effect-e. Unfortunately, merchantable erstories do not always occur on eas capable of producing good ckleberry crops.

Sheep grazing is compatible th huckleberry production, but metimes incompatible with huckle-rry pickers. Wherever possible, azing should be scheduled so that eep are out of the berry fields fore the huckleberries ripen.

Where optimal growth and berry production are desired, nitrogen fertilization is beneficial. Nelson's work (1974) indicated that 40 lb of nitrogen per acre (44.8 kg/ha) produced a response nearly equal to the maximum possible response from field fertilization. To supply this amount of nitrogen, he used 191 lb of ammonium sulfate/acre (214 kg/ha).

If intensive huckleberry management is ever attempted, the young shrubs probably should be planted in heavily used berry fields or recent clearcuttings in berry-producing areas. Cultural techniques are available, and these shrubs can be produced from seed with little difficulty. In high elevation areas where spring frosts cause frequent crop failures, the frost-resistant blueleaf huckleberry could be introduced and managed. It is low-growing and difficult to pick, however, and seems to be less productive than big huckleberry. Mixtures of these two species probably should be grown where frequent frosts occur in the growing season.

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Table 4—Average understory cove

Year and treatment	Big huckle-berry	unch-berry	Noble fir2/3/	Violet	Alpine willow-herb3/	Grand fir2/3/	Total huckleberr competitio
1972 (before treatment):							
Control	22.1	0.1	0	0	0	0	58.8
Borax	23.2	0	0	0	0	0	63.2
Sheep	24.7	0.1	0.1	0	0	0	56.6
Burn	13.4	0	0	0	0	0	65.6
Cut and burn 4/	--	--	--	--	--	--	--
1973:							
Control	13.2	0.1	0	0	0	0.1	53.5
Borax	17.7	0	0	0	0	0.1	56.6
Sheep	11.2	0	0.2	0	0	0	50.7
Burn	5.7	0	0	0.1	0	0	38.9
Cut and burn	4.1	0	0	0.1	0	0	36.5
1974:							
Control	22.5	0.1	0	0	0	0	47.2
Borax	22.0	0	0	0	0	0	50.1
Sheep	21.2	0.1	0.2	0.1	0.1	0	46.3
Burn	15.1	0	0	0	0.1	0	40.7
Cut and burn	3.8	0.1	0	0	0.1	0	42.9
1975:							
Control	22.6	0.2	0	0	0.1	0.2	44.1
Borax	22.7	0	0	0	0.1	0	45.2
Sheep	22.3	0	0.2	0.1	0.1	0.2	40.9
Burn	13.1	0	0	0	0.1	0	33.1
Cut and burn	6.7	0	0	0	0	0	23.3
1977:							
Control	24.4	0.2	0.1	0.1	0	0	57.2
Borax	25.6	0	0	0	0	0	58.9
Sheep	23.7	0.1	0.2	0.2	0	0	56.9
Burn	13.8	0	0	0	0	0	59.4
Cut and burn	11.6	0.1	0	0.1	0	0	54.5

1/ Each average represents 4 tr
significant at P<0.05).

2/ Tallied as understory cover

3/ Absence on most treatment re

4/ No vegetation data were coll

Pesticides used improperly can be injurious to man, animals, and plants. Follow the tions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and ls--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other ating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equip- if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. e a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, et prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing diately and wash skin thoroughly. Spills of herbicides or spray adjuvants should immediately aned from work surfaces and mixing platforms. Spray adjuvants such as Vistik, Dacagin, k, and foaming agents are especially slippery and should be immediately flushed off with water.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. se it is difficult to remove all traces of herbicides from equipment, do not use the same nent for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and regulations. Also, because registrations of pesticides are under constant review by the al Environmental Protection Agency, consult your county agricultural agent or State extension list to be sure the intended use is still registered.

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EXAMPLE 2 (Data from Appendix D):

What is the state of the current at Jacksonville, Florida, off Washington Street, on 12 April 1970 at 0720?

Reference Station	Slack	Maximum Current	Velocity (flood/ebb)	Direction
St. Johns River Entrance, Fla.	0300	0548	1.7 e.	-
Corrections	+220	+250	0.7 (Velocity ratio)	060 (e)
Jacksonville, Fla., off Washington St.	0520	0838	1.2	060 (e)

Interval between slack and maximum current: 0838 - 0520 = 3 hrs., 18 min.

Interval between slack and desired time: 0720 - 0520 = 2 hrs.

Factor (Table 3): 0.8

Velocity: 1.2 x 0.8 = 1.0 kt.

Direction: The current is ebbing. Direction is 060.

Tidal current charts are now available for certain major ports or seaways, to be used in conjunction with the Tidal Current Tables. These charts, prepared by the National Ocean Survey, show hourly directions and velocity of tidal currents. To select which chart to use from a booklet for a given port, determine from the tidal current tables the time difference between the desired time and the nearest preceding slack water; the chart that agrees most nearly with this time computation should be used.

507. CONSIDERATION OF TIDE AND CURRENT

The navigator must fully consider the state of the tide together with charted depth to insure that water is kept under the ship's keel. Tidal ranges may be such as to cause some basins to dry at low tide even though sufficient water is present for safe navigation at high tide. Occasionally the tidal range permits crossing of bars which would not otherwise be navigable.

Knowledge of ocean currents may be used to advantage, either to speed a voyage or to conserve fuel. When standing northeastward through the Straits of Florida, by following closely the axis of the Gulf Stream, the ship's speed may be increased without any increase in engine or shaft RPM. When rounding Florida enroute to the Gulf, the mean axis of the stream should be avoided in order not to slow the speed of advance; actually, a lesser countercurrent to the Gulf Stream may be experienced in close proximity to the Florida Keys, which will be of assistance.

Tidal currents affect a ship considerably when docking, undocking, and whenever underway in pilot waters. A current may be so strong as to prevent a partially disabled ship from making any headway.

The navigator may use both ocean currents and tidal currents to his advantage, and should always be fully conscious of the state of the current and of any expected changes, anticipating how the expected changes, in the state of the current will affect the maneuverability of his ship. As for reliance upon tidal current data, the navigator must expect conditions occasionally other than those predicted. Storm conditions, man-made currents from lock sluice gates or spillways, and currents developed in dredging operations, among others, tend to reduce the accuracy of tidal current data available to the navigator.

CHAPTER 6

DEAD RECKONING

601. INTRODUCTION

Dead reckoning has previously been defined as a method in navigation in which the position of a ship is calculated from the direction and the rate of progress through the water from the last well determined position. The direction and the rate of progress cannot always be measured exactly, and dead reckoning as a method may leave much to be desired. However, when either celestial navigation or piloting is used as a primary means of navigation, dead reckoning provides a check and serves the worthwhile purpose of indicating errors. When other means of navigation fail, the navigator must rely upon dead reckoning alone. Since the automatic dead reckoning equipment is subject to mechanical or electrical failure, the navigator with drafting instruments, and up to date information concerning the ship's movements, manually constructs the dead reckoned plot.

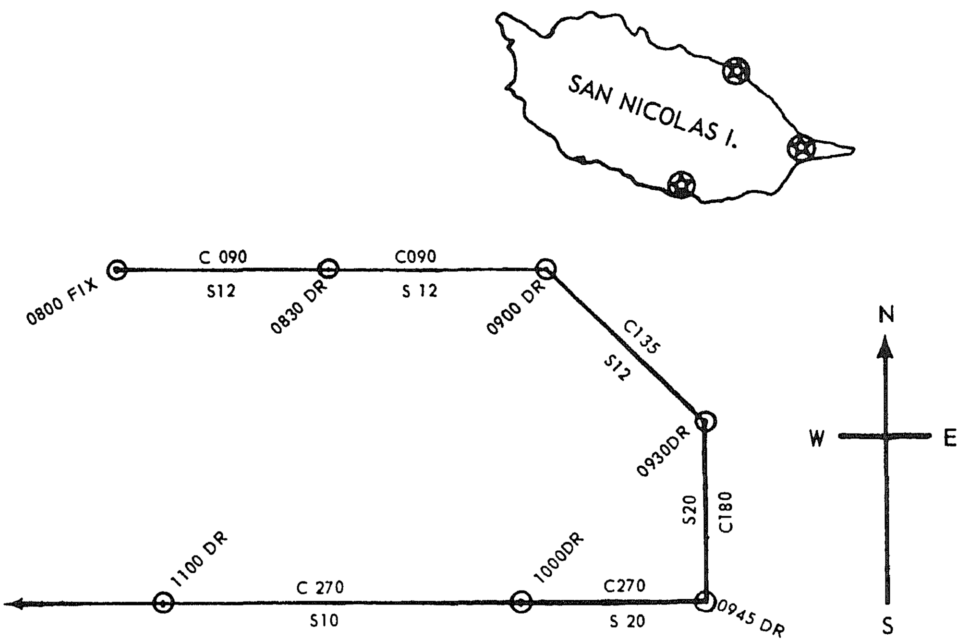
602. THE PLOT

Dead reckoning, as presently accomplished, is a graphic means of navigation. Decades ago, it was accomplished by computation using trigonometric formulae. A dead reckoning plot (fig. 6-1) originates with a well determined position (a fix or running fix as described in the following chapter). From the fix, a course line representing the ship's course is drawn, using the compass rose as a reference. The course line is actually a locus of successive DR positions. Predicted positions, called DR positions, are marked at intervals along the course line. These positions are determined by the speed of the ship, the time interval, and the scale of the chart. For example a ship making a speed of 10 knots would travel 2 1/2 nautical miles in 15 minutes. On a DR course line, using the chart scale, a navigator would set his divider points 2 1/2 nautical miles apart in order to measure from the last well determined position, along the course line, to the predicted posit 15 minutes in the future. The DR plot is fi a prediction of the ship's travel and later graphic history of the route the ship attemp to follow. The course line may be referr to as a DR track or trackline.

When using time and speed to compute d tance in dead reckoning, it is often advantage to use the three-minute rule. Easily prov the rule merely notes that the distance trave in yards in three minutes is 100 times speed in knots. Thus, if a ship is makin speed of twenty knots, it will travel 2000 yar or one nautical mile, in three minutes.

A well determined position is labeled w the time indicated in 4 digits followed by word "Fix;" for example "0800 Fix." Ab a course line, the letter "C" is placed, follow by the ship's true course in 3 digits, indicat the direction of travel; for example, "C09 Below the course line, the letter "S" follow by the ship's speed in knots indicates the r of progress and determines the speed of gene tion of the trackline; for example, "S12." dead reckoned position is labeled with the ti followed by the letters "DR"; for examp "0900 DR." Symbols as well as labels can used to distinguish a fix from a dead recko position. While both are normally indicated a circle around a point, and are distinguis by the letters "fix" or "DR," some navigat follow a former practice of indicating a with a circle and a DR with an arc connect the course lines, an approximate semi-circ

DR positions are usually plotted for e hour. In in-shore navigation the DR should plotted more frequently, perhaps as often every 3 minutes, but always depending u circumstances and proximity to danger. At on a steady course using a small scale ch one DR position plotted each 4 hours is c sidered satisfactory.



190.9
Figure 6-1.—Dead reckoning plot.

By the dead reckoning plot, the estimated time of arrival (ETA) at a destination is computed in advance. Similarly, the estimated time of departure (ETD) from a given point may be calculated unless the point marks the origin of the voyage in which case it is determined by operational planning.

603. CURRENT

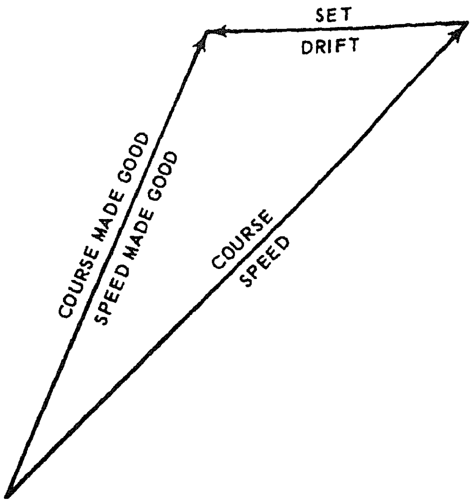
We have previously thought of current as the horizontal movement of water; at this point we must define it for our future convenience, as the total effect of all forces causing a discrepancy between predicted and actual positions. Current when so broadly defined includes the horizontal movement of water, wind effect, steering errors, variations in engine speeds, and any momentary deviation from the basic course made by the conning officer.

Current can be described in terms of two qualities called set and drift. SET is the direction a current acts; DRIFT is the velocity in knots of a current.

To derive set and drift (fig. 6-2), a fix is compared with the DR position for the same time by connecting the DR and the fix with a broken line, terminated by an arrowhead at the fix. This line or vector represents current. The direction of the line (arrow) is the set. The length of the line in nautical miles divided by the hours the current has acted (time interval between last two fixes) is the drift.

The navigator consults current tables, the Coast Pilot or Sailing Directions as appropriate, and pilot charts and draws from his own experience to decide what caused an apparent current. If he decides that the apparent current represents an actual movement of water which can be expected to continue for some time, he may use the determined set and drift of the current to either compute the course and speed essential to making good a desired track or to predict the resultant track for any given course and speed. The accuracy of such computations depends upon the accuracy of the prediction of the set and drift and whether or not any change in the value of the current occurs.

To predict the track using (1) course and speed of the ship and (2) set and drift of the current, represent these basic values by vectors. The direction and length of the ship's vector are based respectively upon the ship's course and speed; the direction and length of the current



58.84C
Figure 6-2.—The current effect.

vector is based upon the current's set and drift. Draw the ship vector for an hour's effect. From the end of the ship's vector, draw the current vector for an hour's effect. The resultant, that is the line connecting the origin of the plot and the terminating end of the current vector, represents the probable track; by inspection of the direction and length of this resultant vector the navigator predicts course and speed made good. The vectors may be drawn in length to represent either an hour or a multiple of an hour. When the navigator prefers the latter representation, and accordingly draws his vectors, then the length of the resultant track is a corresponding multiple of the speed made good.

When it is desired to make good a predetermined track, the first step is to construct the resultant which represents the desired track. From the termination of the desired track (point of destination), the current vector is drawn as the reciprocal of the set, with the length equal to the drift multipled by the time enroute in hours. By completing the triangle the ship's vector is determined; to compute the ship's course and speed respectively, determine the direction of the vector, and its length divided by the duration of the voyage in hours. This plot is of great practical use.

It is no more a safe practice to assume that a current will adhere to a predicted value than it is to assume that no current exists. The cautious navigator will construct on his chart both the DR track based upon course and speed and the predicted track táking current into account. He carefully checks all features between the two tracks, to detect dangers should the current be reduced. He checks features adjacent to and beyond each track to detect dangers should the effect of current either exceed or undergo a reversal in its predicted value. The navigator should assume that the most unfavorable condition of current exists and take appropriate action to insure the safety of his vessel.

CHAPTER 7

PILOTING

701. INTRODUCTION

Piloting has been previously defined as a method of directing the movements of a vessel by reference to landmarks, other navigational aids, and soundings. It is generally used as a primary means of navigation when entering or leaving port and in coastal navigation. It may be used at sea when the bottom contour makes the establishment of a fix by means of sounding possible. In piloting, the navigator (a) obtains warnings of danger, (b) fixes the position frequently and accurately, and (c) determines the appropriate navigational action.

702. LINES OF POSITION

Piloting involves the use of lines of position, which are loci of a ship's position. A line of position is determined with reference to a landmark; in order for a landmark to be useful for this purpose it must be correctly identified, and its position must be shown on the chart which is in use. There are three general types of lines of position (fig. 7-1), (a) ranges, (b) bearings including tangents, and (c) distance arcs.

A ship is on "range" when two landmarks are observed to be in line. This range is represented on a chart by means of a straight line, which if extended, would pass through the two related charts symbols. This line, labeled with the time expressed in four digits (above the line), is a locus of the ship's position. It should be noted that the word "range" in this context differs significantly from its use as a synonym of distance.

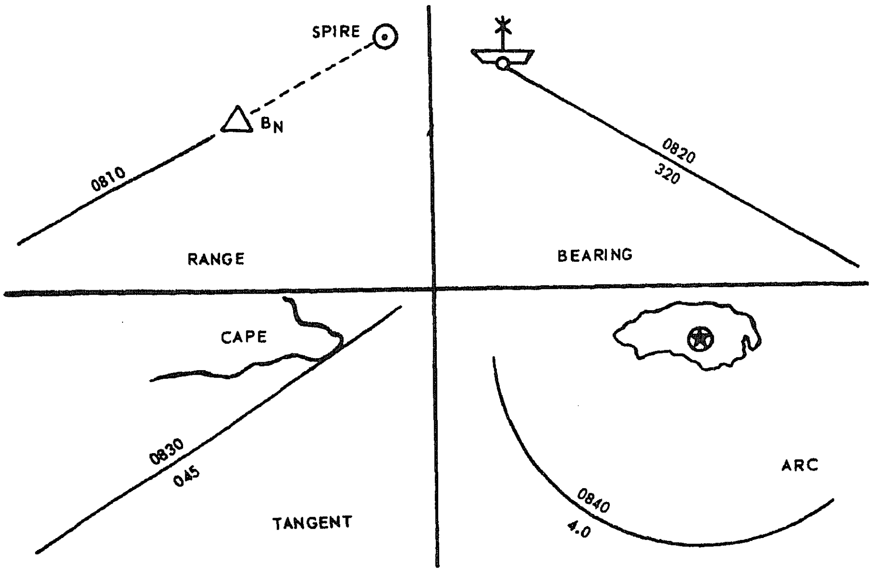
It is preferable to plot true bearings although either true or magnetic bearing may be plotted. Therefore, when the relative bearing of a landmark is observed, it should be converted to true bearing or direction by the addition of the ship's true heading. Since a bearing indicates the direction of a terrestrial object from the observer, in plotting, a line of position is drawn from the landmark in a reciprocal direction. For example, if a lighthouse bears 040, the ship bears 220 from the lighthouse. A bearing line of position is labeled with the time expressed in four digits above the line and the bearing in three digits below the line.

A special type of bearing is the tangent. When a bearing is observed of the right hand edge of a projection of land, the bearing is a right tangent. Similarly, a bearing on the left hand edge of a projection of land as viewed by the observer is a left tangent. A tangent provides an accurate line of position if the point of land is sufficiently abrupt to provide a definite point for measurement; it is inaccurate, for example, when the slope is so gradual that the point for measurement moves horizontally with the tide.

A distance arc is a circular line of position. When the distance from an observer to a landmark is known, the locus of the observer's position is a circle with the landmark as center having a radius equal to the distance. The entire circle need not be drawn, since in practice the navigator normally knows his position with sufficient accuracy as to require only the drawing of an arc of a circle. The arc is labeled with the time above expressed in four digits and the distance below in nautical miles (and tenths). The distance to a landmark may be measured using radar, the stadimeter, or the sextant in conjunction with tables 9 and 10 of the American Practical Navigator.

703. FIXES

A fix (fig. 7-2), previously thought of as a well determined position, may now be defined as the point of intersection of two or more simultaneously obtained lines of position. The symbol for a fix is a small circle around the point of intersection. It is labeled for better identification with the time expressed in four digits



69.141
Figure 7-1.—Lines of position.

followed by the word "fix." Fixes may be obtained using the following combinations of lines of position:

(a) A line of bearing or tangent and a distance arc.
(b) Two or more lines of bearing or tangents.
(c) Two or more distance arcs.
(d) Two or more ranges.
(e) A range and a line of bearing or tangent.
(f) A range and a distance arc.

Since two circles may intersect at two points, two distance arcs used to obtain a fix are somewhat undesirable; the navigator in making his choice between two points of intersection may, however, consider an approximate bearing, sounding, or his DR position. When a distance arc of one landmark and a bearing of another are used, the navigator may again be faced by the problem of choosing between two points of intersection of loci.

704. SELECTING LANDMARKS

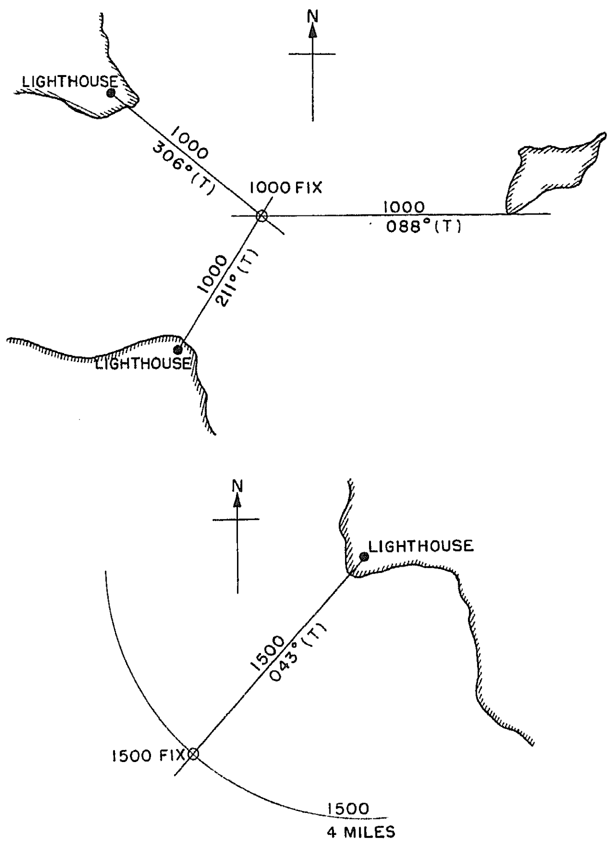
Three considerations in the selecting of landmarks or other aids for use in obtaining lines of position are: (a) angle of intersection, (b) number of objects, and (c) permanency.

Two lines of position crossing at nearly right angles will result in a fix with a small amount of error as compared to two lines of position separated by less than 30 degrees of spread. If in both cases a small unknown compass error exists, or if a slight error is made in reading the bearings, the resulting discrepancy will be less in the case of the fix produced by widely separated lines of position than in that of the fix obtained from lines of position separated by a few degrees.

If only two landmarks are used, any error in observation or identification may not be apparent. By obtaining three or more lines of position, each line of position acts as a check. If all cross in a pinpoint or form a small triangle, the fix may generally be relied upon. Where three lines of position are used, a spread of 60 degrees would result in optimum accuracy.

When a choice of landmarks or other aids exists between permanent structures, such as lighthouses or other structural and natural features identifiable ashore or in shallow water, and less permanent aids such as buoys, the former should be given preference. The fact must be recognized that buoys, while very convenient, may drift from their charted position, because of weather and sea conditions, or through maritime accident.

The navigator oftentimes has no choice of landmarks, their permanency, number, or spread. In such cases he must use whatever is available, no matter how undesirable. In the evaluation of



58.76:.77
Figure 7-2. — Fixes.

his fix, the number of landmarks, their permanency, and their spread should receive consideration. When three lines of position cross forming a triangle, it is difficult to determine whether the triangle is the result of a compass error or an erroneous line of position. The plotting of four lines of position will usually indicate if a line of position is in error.

705. CHANGE IN COMPASS ERROR

When lines of position cross to form a small triangle, the fix is considered to be the center of the triangle, a point which is determined by eye. If the size of the triangle appears significant, it is possible that the value of the compass error has changed.

To compute the new compass error, without the benefit of a range or azimuth, assume an error, then by successive trials and assumptions determine the correct error. If the error assumed is improperly identified (east or west), the triangle will plot larger. If the error proves to be properly identified but the triangle still exists, although reduced in size, the navigator should on the second trial, assume a larger error in the same direction.

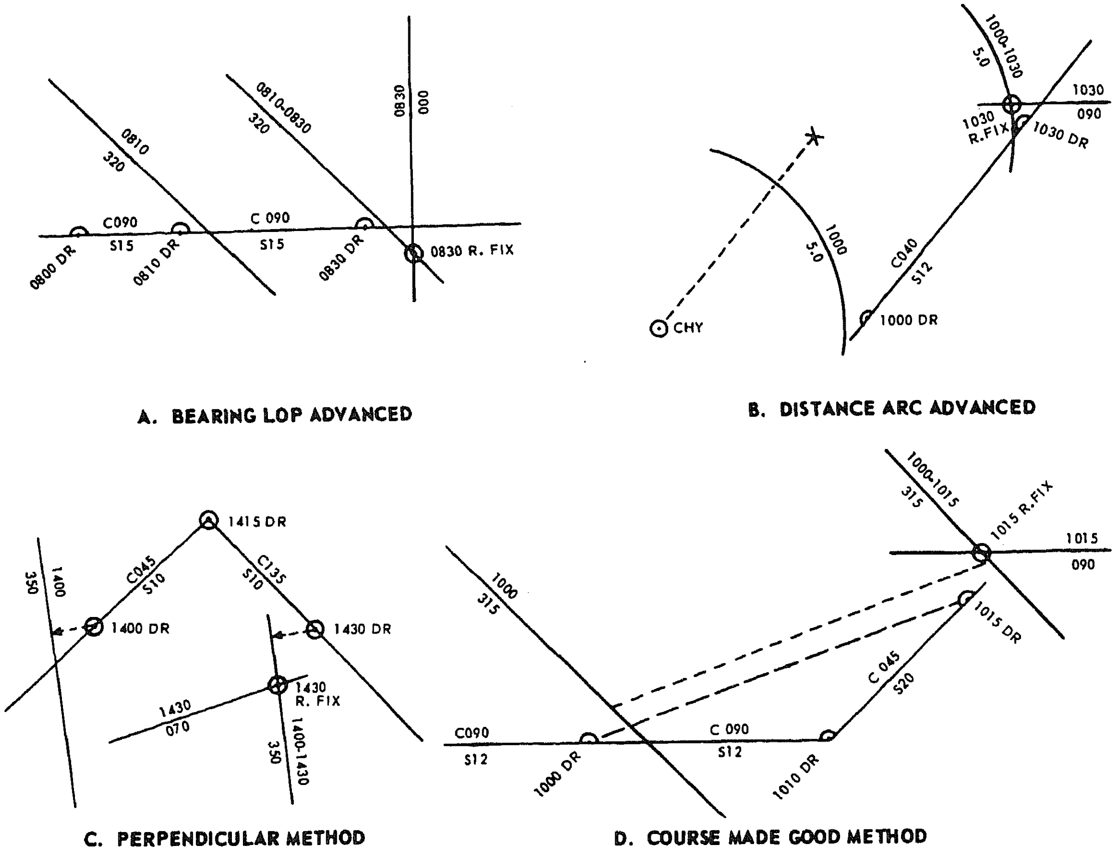
706. RUNNING FIXES

It is not always possible for the navigator to observe lines of position simultaneously. Sometimes only one landmark is available; the navigator may make frequent observations of the one landmark, or he may, after one observation, lose sight of the available landmark only to sight a new navigational aid. During these observations, if the navigator is able to compute distance he may easily establish his fix. If not, or if for any reason his data consists of lines of position obtained at different times, then he may establish a position which only partially takes into account the current. This position is the running fix identified by the same symbol as the fix except that the time label is followed by the abbreviation "R. Fix." It is better than a DR position but less desirable than a fix.

A running fix is established by advancing the first line of position in the direction of travel of the ship (the course), a distance equal to the nautical miles the ship should have traveled during the interval between the time of the first line of position and the time of the second line of position. The point of intersection of the first line of position as advanced, and the second line of position, is the running fix. The advanced line of position is labeled with the times of the two lines of position (LOP's) separated by a dash, and the direction, above and below the line, respectively. See fig. 7-3.

To advance a line of bearing, a tangent, or a range, measure from the point of intersection of the LOP and the DR track line, along the track line, the distance the ship would have traveled at its given speed. This measurement provides a point on the DR track line, through which the earlier line of position is re-plotted without any change in its direction. (Fig. 7-3A.)

To advance a distance arc, draw the course line as a broken line on the chart from the landmark first observed. Along this broken course line, measure the distance the ship should have traveled, based upon the elapsed time between observations and the speed of the ship. At the point thus established, reconstruct the earlier distance arc. (Fig. 7-3B.)



58.76(190)
Figure 7-3.—Running fixes.

If the ship changes course and/or speed between observations the problem is not so simple to solve, and one of the following methods should be used:

PERPENDICULAR METHOD.—After two lines of position are obtained, plot DR positions corresponding to the times of the LOPs. From the earlier DR, drop a perpendicular to the earlier LOP. At the second DR, construct a line having the same direction and length as the first perpendicular. At the termination of the latter line, construct a line parallel to the original LOP; this is the advanced LOP. The intersection of this advanced LOP and the last observed LOP establishes the running fix. The logic of the perpendicular method is that since the speed and course of the ship generates the DR track line, if the advanced LOP lies with respect to the second DR position as it previously lay with respect to the old DR, then it has been advanced parallel to itself a distance and a direction consistent with the ship's movement during the intervening time. A variation of this method is to construct, instead of a perpendicular, a line of any direction between the first DR and LOP. This line is then duplicated at the second DR and the LOP advanced as before. In duplication the line from the second DR must be of the same length and direction as the line connecting the first DR and LOP. (Fig. 7-3C.)

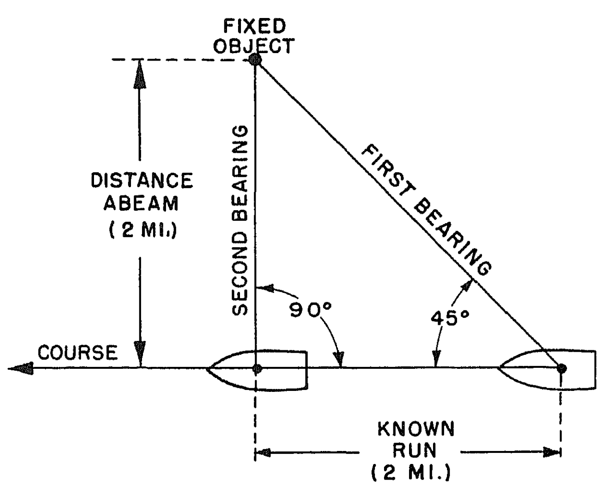
COURSE MADE GOOD METHOD.—As in the perpendicular method, plot DR positions to match the time labels of the LOP's. Connect the DR positions; the connecting line represents the course and distance which the ship should have made good. Advance the first LOP a distance and direction corresponding to the line connecting the two DR positions. (Fig. 7-3D.)

DRAI METHOD. —Since the DRAI resolves received inputs into components (N or S, E or W) the components for a given run may be plotted and connected by a line. The hypotenuse of the right triangle thus formed represents the direction and distance the first LOP should be advanced.

707. SPECIAL CASES

A special case of the running fix is the "bow and beam" situation. (See fig. 7-4.) When the bearing of a landmark diverges 45 degrees from the ship's heading, it is said to be broad on the bow. When the divergence increases to 90 degrees, it is on the beam. By noting the time a landmark is broad on the bow and the time it is on the beam, the distance passed abeam can be computed; the distance abeam will be equal to the distance run between bow and beam bearings which in turn will depend upon the elapsed time and the ship's speed. Knowing the distance abeam, when a beam bearing is observed, makes the plotting of the running fix quite simple. The true bearing will be the true heading plus or minus 90 degrees depending upon whether the landmark is abeam to starboard or abeam to port. The distance run equals the distance abeam because 45 and 90 degree angles provide a right isosceles triangle with equal sides.

Another special case, which is related to that of the bow and beam, is one known as "doubling the angle on the bow." The angle formed by the course of the ship and a sight line in the direction of a navigationally useful object is observed and noted, together with the time. A second observation is made and the time noted when the angle on the bow is double that of the first observation. At that instant, the distance from the object is equal to the distance run between observations.



58.79
Figure 7-4. — Bow and beam bearings.

The triangle formed by two bearings and the course line is a right isosceles triangle in the special bow and beam case which we have seen. However, it can be easily proved that upon doubling the angle on the bow, the triangle thus formed is also an isosceles triangle, having two equal sides, although not usually a right triangle.

708. RUNNING FIX ERRORS

The running fix may be a well determined position and is usually considered as such. For this reason, the DR track is normally replotted using the running fix as a new point of origin.

However a running fix does not fully account for current, and the displacement of the running fix from the DR is not a true indication of current. If a head current is expected, extra allowance should be made for clearance of dangers to be passed abeam, because the plot of running fixes based upon any single landmark near the beam will indicate the ship to be farther from that danger than it actually is. If a following current is experienced, then the opposite condition exists. This occurs because the actual distance made good is less with a head current and greater with a following current than the distance the LOP is advanced based upon dead reckoning. Usually, a limitation of 30 minutes should be imposed on the elapsed time between lines of position in a running fix; this however, is not a hard rule because of other considerations.

709. ESTIMATED POSITION

While it may not be feasible for the navigator to obtain either a fix or a running fix, he may observe such data as to make possible the plotting of a position more probable than a DR. Such a position is called an estimated position. It is identified as a square with a dot in the center and labeled with the time in four digits followed by the letters "EP."

If the navigator has computed or knows the approximate strength of the current, this information may be applied to obtain an EP. At any DR position, construct the current vector; the direction of the vector will represent the set and

the length of the vector will depend upon the drift and the elapsed time since the last fix. The point of termination of this vector is the estimated position.

Occasionally in reduced visibility the navigator may sight an aid momentarily and establish an EP. An EP may identify a fix or running fix which, in the judgment of the navigator, has been inaccurately obtained, or a fix obtained using radio bearings.

When a vessel passes over a bottom having abrupt changes in depth or irregular contours, soundings may be utilized in the establishment of an EP. The navigator directs the recording of soundings at regular intervals. If these soundings are obtained using the fathometer then the draft of the ship is added to all values. His data then consists of depth recorded against time. A sheet of paper is graduated on one edge with the space between marks corresponding to the distance run (as measured on the scale of the chart in use) between the recording of soundings. These marks are labeled with time and depth. The navigator places the sheet on the chart with the labeled edge of the sheet in the general vicinity of the DR track. He moves the paper laterally in an effort to match the depths on the paper with charted depths (bottom contour). In lieu of the use of a sheet of paper on which the edge serves as the DR track, a sheet of flimsy paper with the DR track drawn anywhere on it, may be marked with soundings and used. If successful, the navigator may locate an estimated position by this procedure.

Whether the navigator considers the DR or the EP as the ship's actual position depends upon the proximity of danger to each position with the track extended ahead, whichever position and track is nearest danger should be considered as the actual position and track in order to provide the widest margin of safety.

710. FIXES BY SOUNDING

A new and rather unique piloting procedure has evolved whereby a fix instead of an EP can be obtained by soundings. This new procedure is characterized by the use of bottom contour lines as lines of position.

By this method, it is first necessary to record the time of crossing each bottom contour line, together with the sounding. Second, it is necessary to indicate on the DR track the DR positions for times that such soundings were taken. Third, on a sheet of flimsy paper a line is drawn with an arrow on one end to indicate the direction of travel; a dot is placed approximately three inches back of the arrow point as a reference mark. Fourth, the flimsy paper is placed over the DR track with the reference dot over the DR position corresponding to the first recorded sounding and with the arrow in the direction of travel; the contour of the sounding recorded at that time is traced and labeled. Fifth, by moving the sheet in the direction of travel, and with the reference dot over successive DR positions, corresponding contour lines are identified by sounding and traced. Finally, after three or more contours are plotted, the intersection of contours may indicate a fix. It should be remembered that contour lines because of their irregularity may cross at more than one point, and thus several may need to be plotted to resolve possible ambiguity. The time of the fix corresponds to the time of the last plotted sounding.

EXAMPLE: Having noted the bottom contour lines on the chart in use, the following soundings were taken and recorded.

Time	Sounding
1000	110 fms.
1005	110 fms.
1007	120 fms.
1010	130 fms.
1015	140 fms.

Preparation:

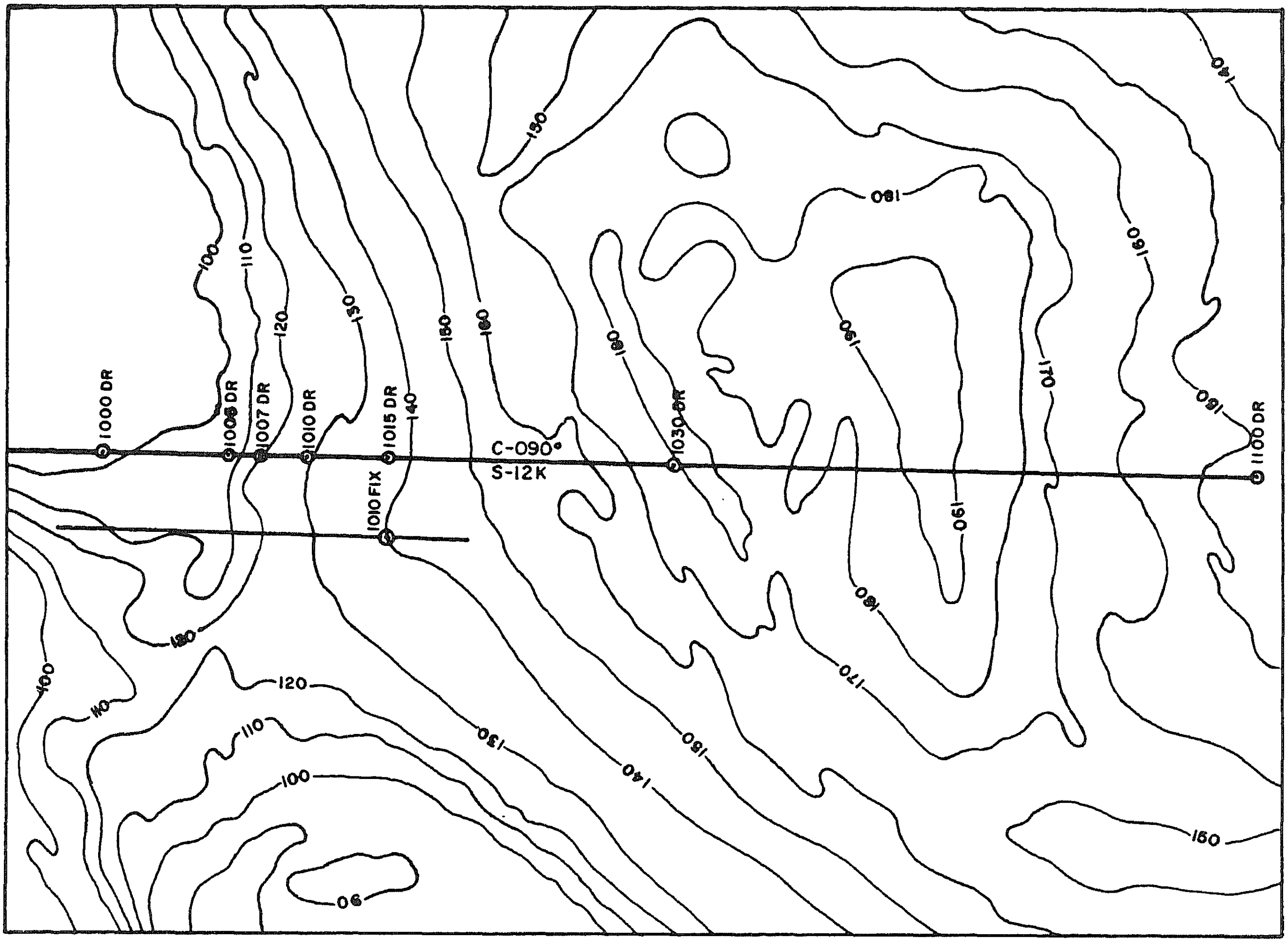
Having recorded the time of crossing of each contour, as indicated by sounding, on the chart, place the ship's DR track on the chart and indicate the DR position for each of the times recorded. (Fig. 7-5.)

Take a sheet of flimsy paper, draw a line across the sheet, and place an arrow point on one end of the line to indicate the direction of travel. Place a reference dot approximately three inches behind the head of the arrow. (Fig. 7-6A.)

Plotting:

Step 1 — Place the flimsy paper over the chart with the dot over the first DR position and the arrow pointing in the direction of travel. Trace the contour of the sounding recorded at that time and label with sounding. (Fig. 7-6A.)

Step 2 — Move the flimsy sheet in the direction of travel until the dot is over the second DR



58.79(190)
Figure 7-5.—Fix determined by sounding.

position. Trace the contour of the sounding recorded for that time and label with the sounding. (Fig. 7-6B.)

Step 3—Move the sheet in the direction of travel until the dot is over the third DR position. Trace the contour of the sounding recorded for that time and label with the sounding. Examine for possible fix results. (Fig. 7-6C.)

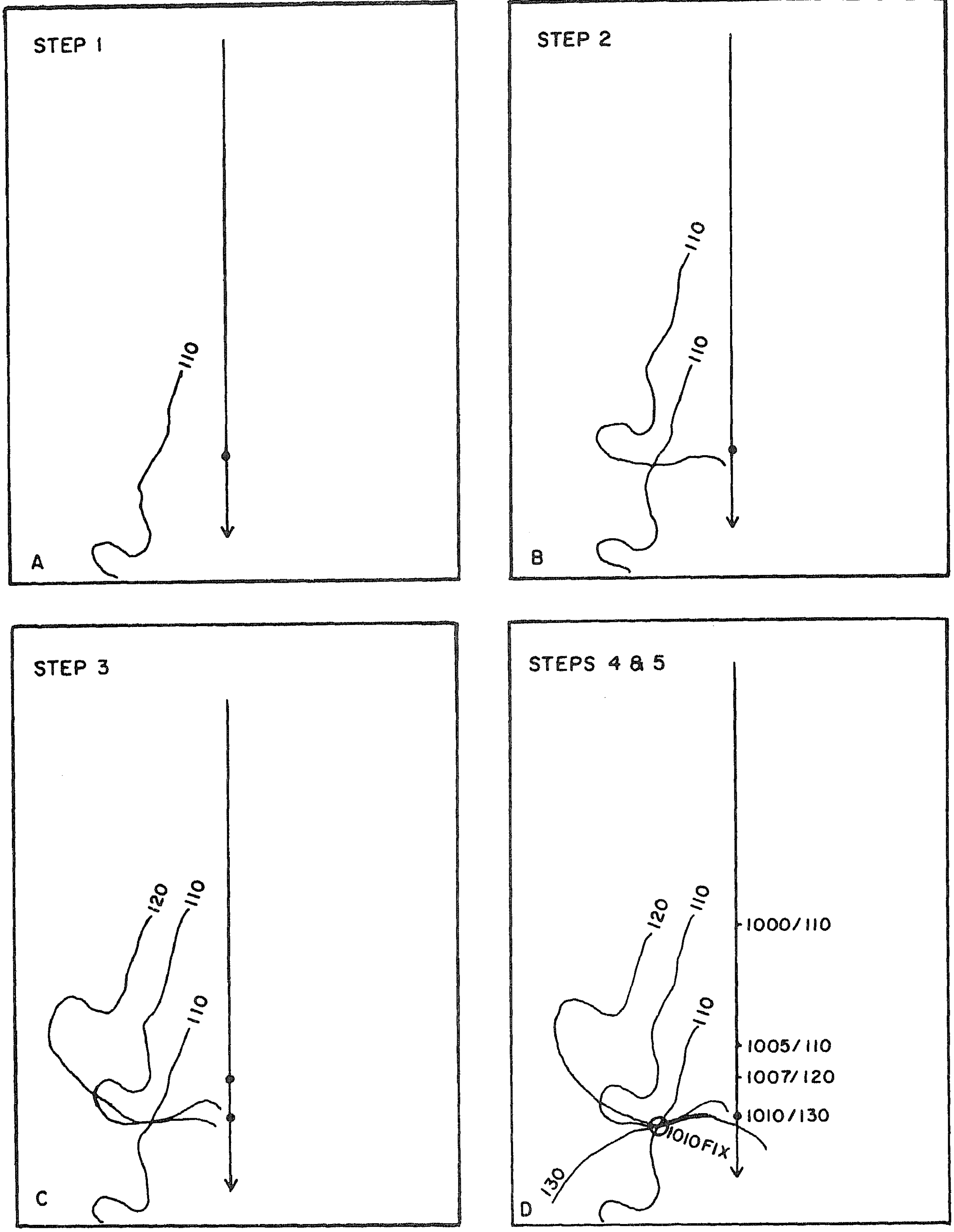
Step 4—Move the sheet in the direction of travel and trace the next sounding as in steps 1 through 3. The position of the fix should be apparent. The time of the fix when located will be the recorded time for the sounding last used for fix information. (Fig. 7-6D.)

Step 5—Since sounding contours are not usually straight lines and can cross in more than one place, the position must be checked by placing the DR, with both time and soundings, on the flimsy paper. Place the last DR time over the newly obtained fix and check the times and soundings against the apparent track. (Figs. 7-6D and 7-5.)

It may be noted that the position obtained by this procedure is technically a running fix, rather than a fix. Dependent upon the amount of elapsed time and the correlation of track and soundings, the position obtained may be considered as a fix, a running fix, or an estimated position.

711. DANGER BEARINGS AND DANGER ANGLES

It is possible to keep a ship in safe water without frequent fixes through the use of danger bearings and danger angles.



190.10
Figure 7-6.—LOP and fix determination by sounding.

If a ship must pass a dangerous area such as unmarked shoal water, draw a circle around the area on the chart. Check the chart for some prominent landmark in the general direction of travel (or the reciprocal). Draw a line from the landmark tangent to the danger circle and label the line with its direction. This direction is the danger bearing on the landmark from which it is drawn. With the danger bearing as a line of demarcation, the mariner can tell whether he is outside or inside of the danger area just by checking the bearing of the object.

Danger angles are of two types, horizontal and vertical. If two prominent landmarks are available, a horizontal angle is used. If only one prominent landmark is available then a vertical angle is used; however, this method requires that the height of the landmark be known. In either case the first step is to draw a circle around the danger area on the chart. For a horizontal angle, a circle is constructed passing through the two available prominent landmarks, and tangent to the danger circle. If it is desired to leave the danger area between the ship's track and the selected landmarks, the circle through the landmarks contains the danger circle; if it is wished to pass between the danger circle and the prominent landmarks, the danger circle although tangent, will lie outside the circle which passes through the selected landmarks. To construct two circles tangent to each other, it is necessary to make use of the fact that their diameters lie in a straight line. From the point of tangency of the two circles draw two chords, one to each landmark. These chords provide an inscribed angle the value of which is the danger angle. To leave the danger area between the track and the selected landmarks, the angle formed by the two landmarks with the ship's position as a vertex must not be allowed to become greater than the danger angle. To pass between the two prominent landmarks and the danger area, the angle must not be allowed to become smaller than the danger angle.

To use a vertical angle, construct a circle tangent to the danger circle, using the landmark of known height as the center. The vertical danger angle may be found by entering table 9 of the American Practical Navigator with the radius of the tangent circle and the height of the object.

To pass between two danger areas, the navigator computes an upper and a lower limitation for the value of the danger angle.

712. TACTICAL CHARACTERISTICS IN PILOTING

Thus far in this discourse upon piloting, the tactical characteristics of the ship have not been considered. It has been assumed that course and speed changes would be effected instantaneously. In actuality, such is not the case. At sea, when at great distance from navigational hazards, such an assumption can be made, inasmuch as the ship is in no immediate danger, and on a small scale chart the tactical characteristics will not alter the plot. However, most piloting is accomplished inshore, in close proximity to navigational hazards. Large scale charts enable the navigator to depict his position with greater accuracy as essential for ensuring safe passage. Accordingly, the largest scale, most detailed charts available are used when in restricted or pilot waters, and full allowance is made for the tactical characteristics of the ship.

Tactical characteristics vary with each ship. To effect either a course or a speed change requires varying amounts of time and space, dependent upon the ship, the magnitude of the change, sea and weather conditions. Particularly in effecting a course change, the ship may be expected to be offset some distance from the planned track unless the turning characteristics are considered. Failure to consider such characteristics can directly contribute to driving the ship into danger.

Tactical data is obtained and recorded for each ship to describe turning characteristics in terms of "advance" and "transfer" for varying rudder angles, usually every 15°. "Advance" is the distance gained along the original course extended, and "transfer" is the distance offset perpendicular to the original course; both are measured from the point at which the rudder is put over. Advance is maximum for a turn of 90°.

Other related terms include:

Angle of turn — The arc in degrees through which a ship turns.

Turning circle — The path followed by the pivot point of a ship turning 360°.

Tactical diameter — The distance offset right or left of the original course when a turn of 180° is made.

Final diameter — The distance perpendicular to the original course as measured between tangents to the turning circle at 180° and 360° points in the turn. Essentially, it is the diameter of the turning circle. The final diameter is always somewhat less than the tactical diameter.

Standard tactical diameter — A prescribed distance used by all ships in a formation as a tactical diameter for uniformity in maneuvering.

Standard rudder — That amount of rudder required for a ship to turn in its standard tactical diameter.

Tactical data also includes tables of acceleration and deceleration to accommodate the need for accurate calculation of a ship's progress along the planned track.

In restricted or pilot waters, the need for accuracy is generally so great, that advance and transfer must be considered before each course change. Accordingly, advance and transfer are estimated, and at that point on the chart where the course change is to be effected, it is plotted in reverse direction. This identifies the point at which the rudder should be put over to effect the course change in a timely fashion. Additionally, the bearing of a landmark or other aid to navigation, preferably close to the beam, should be noted, as measured from that point on the plot at which the rudder will be put over. This bearing, termed the "turn bearing," is used as one means of ascertaining the proper time for making the turn. However, it is always good practice to obtain a fix a minute or so before the turn, and an additional fix after the turn when the ship is steady on its new course.

In addition to allowing for advance and transfer in making a turn, the combined effect of wind and current should be considered. The wind can be observed, and the current can generally be predicted, as we have seen previously, from tables. Experience in ship handling and knowledge of local sea and weather conditions are most helpful, and provide reason for navigation being an art as well as a science.

713. PRECISION ANCHORING

For practical convenience, the Oceanographic Office publishes anchorage charts of principal U.S. ports. These are merely harbor charts with anchorage berths preselected and overprinted as colored circles of various diameters. Anchorage berths, with centers usually in a straight line, and with limiting circles usually tangent to those adjoining, are identified by letters and/or numbers for simplification of anchorage assignment. For anchorage in an area in which such berths are not readily available, it is the usual practice to specify or locate the anchorage in terms of bearing and distance from a prominent landmark.

The requirement for anchoring should be anticipated, and except in an emergency situation, deserves detailed preparation. The location must be studied, noting the depth of water, nature of bottom, and the navigational aids useful for accurately fixing the position during the approach, upon, and after anchoring. The proximity of navigational hazards, and the proximity of channels or fairways subject to ship traffic, should be considered. The nature or type of bottom is an indication of the holding qualities; for example, the anchor will hold better in mud or clay than in sand or rock, and will usually hold better in sand than on a rock bottom. The type of bottom, depth of water, and anticipated weather, should be considered in planning the scope of anchor chain, in addition to the proximity of other ships, underway or at anchor, and navigational dangers.

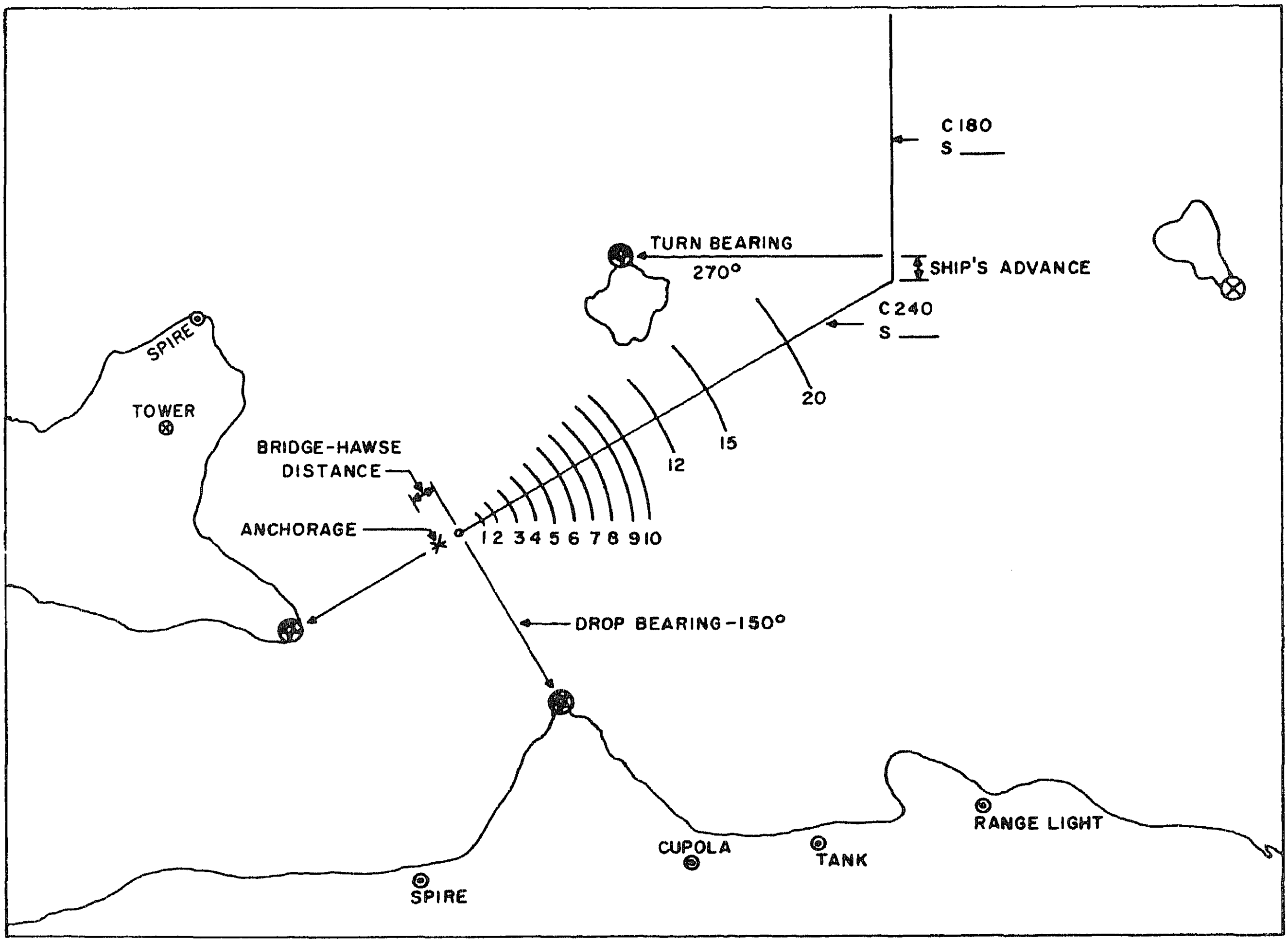
A planned track must be prepared to the anchorage, with careful consideration of all hydrographic features and the draft of the ship. Consideration must be given to the raising of the pit sword or rodmeter, if extended, and of the type which can be raised and housed. Wind and current must be considered. It is advantageous to approach the anchorage, when possible, by heading directly into the current, except when the wind effect exceeds that of the current, in which case it is advantageous to head into the wind. Such contributes to greater steering accuracy, which can be further improved by the ship maintaining a steady course for at least the last 500 yards to the anchorage. The location of navigational aids should be fully considered. If wind and current conditions will also permit approaching the anchorage with the ship "on range," which is the maintaining of two fixed objects in line with the direction of the line corresponding to heading, then even greater navigational accuracy can be achieved. The navigator can thereby practically eliminate the effect of compass error on steering. He can determine the ship's progress along the approach track merely by observing and plotting one cross bearing, although the plotting of two such cross bearings is more desirable.

In further preparation, the navigator should consider the distance from the bridge, where the bearings are to be taken, to the hawse pipe, at which point the anchor is to be dropped; this is known as "bridge-hawse distance." Converted to yards, and measured along the track from the anchorage in opposite direction of the approach, the bridge-hawse distance identifies that point which when reached by the bridge, places the

hawse in the proper position for anchoring, assuming that the heading of the ship corresponds to the direction of the approach track. Appropriately, the bearings upon anchoring will normally be observed from the bridge, and when plotted should fix the ship's position that distance away from the desired anchorage as is equal to the bridge-hawse distance in a direction which is the reciprocal of heading. Also, the navigator should strike arcs of range circles, from the point established using bridge-hawse distance, so that the distance to anchorage can be directly read from the plot without resort to direct measurement. Arcs of range circles are usually drawn, crossing the approach track, using radii in 100 yard increments out to 1000 yards, with additional arcs at 1200, 1500, and 2000 yards. Labeling the point for letting go the anchor as 0, the other arcs are labeled in accordance with their represented range from the anchorage. (See fig. 7-7.)

If turns are to be made in the approach, the navigator should note and record the "turn bearings" of suitable navigational aids. The immediate availability of turn bearings, together with an estimate of advance and transfer, will serve the navigator in effecting the turn with accuracy. Additionally, he will note and record the "drop bearing," that is, the bearing of a prominent landmark which is approximately perpendicular to the approach track. Allowance for the bridge-hawse distance is made in determining the drop bearing.

It is common practice for the navigator, well prior to anchoring, to inform the Commanding Officer, the Officer of the Deck, and the First



190.11
Figure 7-7. — Preparation for precision anchoring.

Lieutenant of the depth of water, the type of bottom, and the distance and location of shoal water or other navigational hazard in the vicinity of the planned anchorage. Before the approach, the navigator should show the Commanding Officer and Officer of the Deck the approach track and inform them of the principal landmarks to be used, of turn bearings if any, and of the drop bearing. Throughout the approach, the navigator will report the direction and distance to anchorage.

It is good seamanship practice under most conditions for the ship's headway to be reduced as it approaches the anchorage, and upon reaching the drop bearing, in anticipation of which propellers are reversed, to let go anchor with a small amount of sternway on. This generally makes it possible to set the anchor without its chain tending under the ship where it may endanger such appendages to the underwater body as the sonar transducer. By a careful combination of engine orders and the holding or veering of chain, the anchor can usually be safely set.

Upon anchoring, it is necessary to accurately fix the position by observing and plotting a round of bearings. As soon as the anchor is known to be holding, the position should again be fixed. Additionally, by using a sextant and a three-arm protractor as explained in art. 310, with sextant measurement of horizontal angles as observed from the forecastle (at the hawse, when the chain is nearly vertical), an accurate fix can be obtained. This can serve as a check upon the fix based upon bearings observed from the bridge. While at anchor, bearings are taken and recorded periodically for comparison with the established fix as a precaution against dragging.

Upon getting underway from anchor, the navigator must commence piloting procedures as soon as the heaving in of the anchor chain is commenced. The ship's position must be accurately known, particularly from the time the anchor breaks ground. During this crucial period in getting underway from anchor, accurate knowledge of the ship's position is necessary as a precaution against dragging or drifting into shoal water or other hazard.

714. BUOYAGE

Buoys are navigational aids which serve as markers. Some are so equipped as to be useful at night or during periods of reduced visibility; some are not so equipped and hence are useful only in daytime. Buoys are not fixed aids (they consist of a float, mooring, and anchor) and can not be completely relied upon. Their service is chiefly that of warning the navigator of impending danger. The following are representative types (descriptive of the float, which identifies a buoy):

SPAR BUOY.—A trimmed log which resembles a stake at a distance.

CAN BUOY.—A cylindrical steel float.

NUN BUOY.—A steel float the shape of a truncated cone.

BELL BUOY.—A buoy with a skeleton tower which holds a bell generally actuated by the motion of the sea. Some bells are struck by the action of gas compressed in a cylinder.

GONG BUOY.—Similar to a bell buoy but equipped with gongs instead of a bell, which make sounds of different tones.

WHISTLE BUOY.—Similar to a bell buoy but equipped with a whistle (useful in low visibility) usually actuated by the motion of the sea. Some buoys are equipped with trumpets which are sounded mechanically.

LIGHTED BUOY.—Buoy which carries a light at the top of the skeleton with either acetylene gas or electric batteries for power. A lighted buoy may for some reason become extinguished and therefore is not completely reliable.

COMBINATION BUOY.—A buoy which combines a light signal with a sound signal. Examples are lighted whistle buoys, lighted bell buoys, and lighted gong buoys.

RADAR REFLECTOR BUOY.—A buoy which supports a screen and makes early detection by radar probable.

Buoys which mark turning points may be equipped with a ball, cage, or some other device.

Each maritime country has developed, and in most cases, standardized by law, the colors for its own particular buoyage system. These systems are described in appropriate Oceanographic Office Sailing Directions. The following colors represent U.S. buoys and, with the exception of white and yellow, indicate lateral significance:

RED.—Identifies buoys on starboard hand of a channel entering from seaward. A rule to

remember is "3R's" meaning "Red-Right-Returning." These buoys are usually of any type except can, and bear even numbers commencing with 2 at the seaward end of a channel. They may carry a red or white light.

BLACK. — Identifies buoys on the port hand of a channel entering from seaward. These buoys are usually of any type except nun, and bear odd numbers commencing at the seaward end of the channel with 1. They may carry a green or white light.

RED AND BLACK HORIZONTALLY STRIPED. — Identifies an obstruction or junction and may be passed on either hand.

BLACK AND WHITE VERTICALLY STRIPED. — Identifies a fairway or midchannel buoy which should be passed close aboard. Only white lights are carried by this type of buoy.

WHITE. — Anchorage.

YELLOW. — Quarantine anchorage.

Beacons, stakes, and spindles may be erected in shallow water. Their color is in accord with the buoyage system but usually also provides a contrast with the background. These are fixed landmarks and are generally more reliable than buoys.

Representative lighted and unlighted buoys, as well as various beacons, are illustrated in Appendix A.

715. LIGHTS

Lighted aids consist of lightships, lighthouses, lighted beacons, and lighted buoys. These are listed in the light list to facilitate identification. Failure to correctly identify a light has often resulted in disaster; light identification requires corrected charts and publications, and warrants the use of a stop watch to check the period or cycle. Characteristics of lighted buoys are illustrated in Appendix A.

Light colors may be white (W), red (R), or green (G). If not indicated, the light is assumed to be white.

The period of a light is the time in seconds a light requires to complete a cycle, or endure a complete set of changes.

716. VISIBILITY OF LIGHTS

Light visibility is categorized by three types of ranges, geographic, nominal, and luminous.

The Geographic visibility of a light is the number of nautical miles a light may be seen by an observer at a height 15 ft. above sea level, under conditions of perfect visibility, and without regard to candlepower. The geographic visibility and the height of a light may be found on the chart, adjacent to the light symbol, and in the Light List. The higher the light the greater the distance it should be seen; theoretically, the distance a light should be seen by an observer at sea level is the length of a beam measured from the light to its point of tangency with the earth's curved surface, assuming that the light is not restricted by candlepower or brilliancy.

The nominal range is the maximum distance at which a light may be seen in clear weather, which is meteorologically defined as a visibility of ten nautical miles. Nominal range is listed for only those lights having a computed nominal range of five nautical miles or greater. If the geographic range is greater than the listed nominal range, the latter will normally govern.

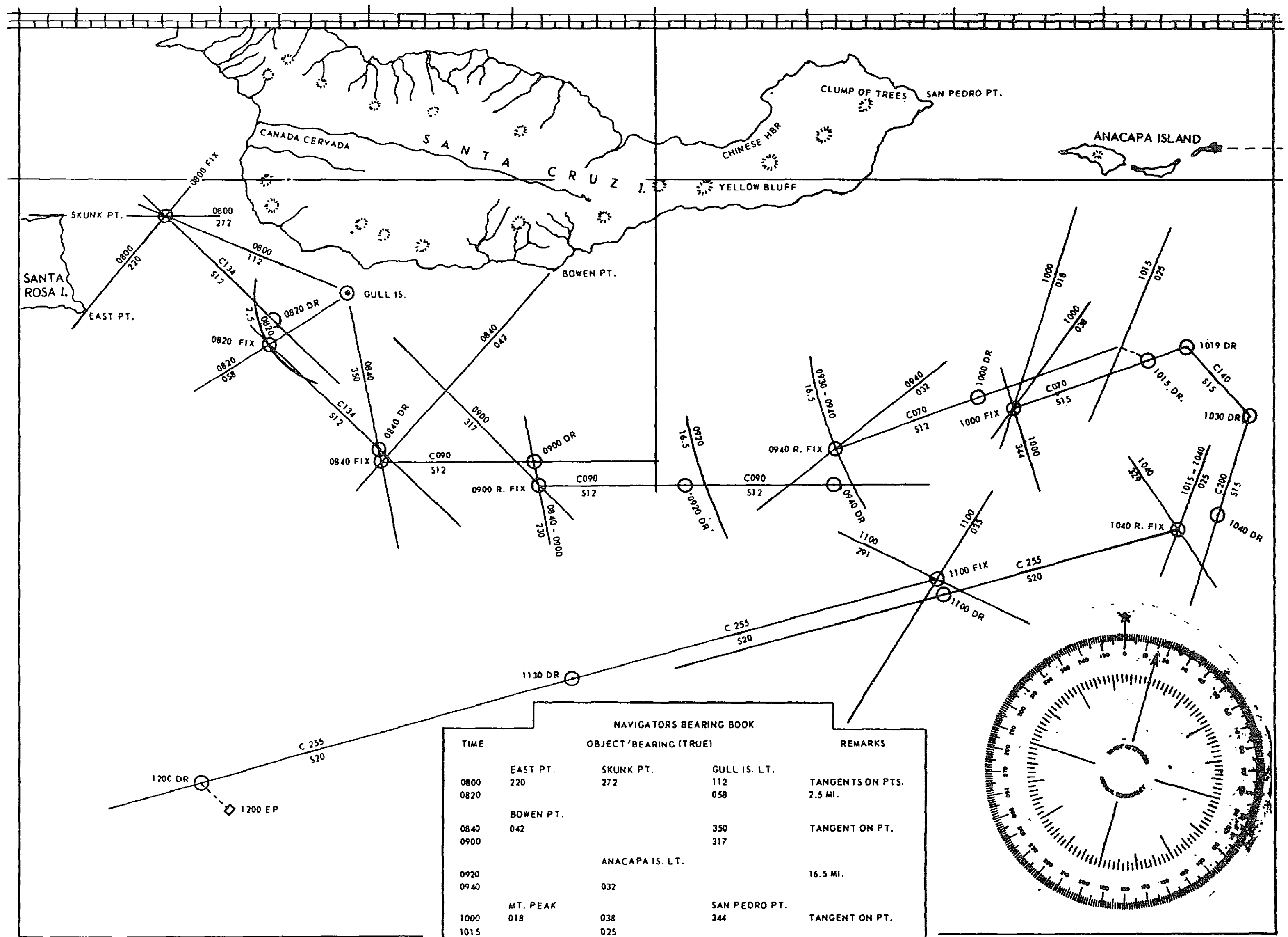
The luminous range is the maximum distance a light may be seen under existing conditions of visibility. The luminous range is determined from either the nominal range or the intensity, and the existing conditions of visibility. See Appendix E.

Intensity or candlepower of light given is approximate and is based upon the International Standard Candela.

The navigator is interested in the radius of visibility of a given light under existent conditions. Thus, the navigator normally determines luminous range, then computes that limitation imposed by the earth's curvature; by comparison, it can readily be seen which limitation is applicable, that determined by intensity or that imposed by the heights of the light and of the observer's platform.

Using the luminous range diagram (Appendix E), either the nominal range or the intensity, and the meteorological visibility, the luminous range can be found by inspection. Using the distance of visibility of objects at sea (Appendix E), the height of the light, and the navigator's height of eye, the distance a light can be seen as limited by earth's curvature can be computed; values as taken from the table of distance of visibility for each of the two heights are simply added. The radius of visibility of the light will equal the lesser of these two range limitations, luminous and earth's curvature.

The applicable Light List provides the heights of lights, and as appropriate, the nominal range and intensity. The navigator must know his own height of eye and the meteorological visibility.



NAVIGATORS BEARING BOOK

TIME	OBJECT/BEARING (TRUE)			REMARKS
	EAST PT.	SKUNK PT.	GULL IS. LT.	
0800	220	272	112	TANGENTS ON PTS.
0820			058	2.5 MI.
	BOWEN PT.			
0840	042		350	TANGENT ON PT.
0900			317	
		ANACAPA IS. LT.		
0920				16.5 MI.
0940		032		
	MT. PEAK		SAN PEDRO PT.	
1000	018	038	344	TANGENT ON PT.
1015		025		
1040			329	
	GULL IS. LT.			
1100	296	035		

NOTE: AT 1200 THE NAVIGATOR ASSUMED A CURRENT WITH A SET OF 135, DRIFT 1.0 KNOT IN ARRIVING AT AN ESTIMATED POSITION.

69.143

Figure 7-8.—Piloting plot and bearing book.

EXAMPLE 1:

Given: Light, 55 feet high, geographic range 13 miles, nominal range 11 miles, intensity 2,000 Candelas. Navigator's height of eye, 27 feet; visibility 5 miles.

To find: Radius of visibility.

Solution: Enter the luminous range diagram (Appendix E) with (1) either the nominal range or the intensity; and (2) the meteorological visibility. When both nominal range and intensity are given, it is preferable to enter the diagram with intensity. It may be determined that the luminous range is 7 miles. Since the navigator is at a greater height than that upon which geographic range is computed (15 feet), he should be able to see the light at least 13 miles away (its geographic range), unless limited by its intensity. Using the distance of visibility of objects at sea as tabulated in Appendix E, the distance visible as limited by the earth's curvature is computed as follows:

height of light,	55 feet -	8.5
height of eye,	27 feet -	6.0
	Total -	14.5 nautical miles

However, since the light is limited by intensity and existing visibility, the luminous range is applicable, and the radius of visibility is 7 miles.

EXAMPLE 2:

Given: Light with same characteristics as in Example 1. Navigator's height of eye is 10 feet; visibility is 20 miles.

To find: Radius of visibility.

Solution: The luminous range based upon the diagram, is found to be 16 nautical miles. The range, based upon the earth's curvature, is determined as follows:

height of light,	55 feet -	8.5
height of eye,	10 feet -	3.6
	Total -	12.1 nautical miles

Thus, the radius of visibility, in this case, as limited by the earth's curvature, is about 12 nautical miles.

It should be noted that if the characteristics of a light and the distance to it upon sighting are known, the luminous range diagram may be used to determine the meteorological condition of visibility.

717. PREDICTING THE SIGHTING OF A LIGHT

Having computed the radius of visibility, draw a circle using the computed radius with the light as center. The point of intersection of this circle and the DR track marks the point at which a light should be sighted. This time is computed by dead reckoning; the true bearing is the true direction of the light from the point of intersection of the DR track and the circle.

718. LIGHT SECTORS

Shield or colored glass shades may be fitted to lights making them obscure in one or more sectors or so that they will appear to be one color in certain sectors and a different color in other sectors. These sectors may be located on the chart by dotted lines and color indications. Such sectors are described using true direction in three digits for each sector boundary, and the direction given is as observed from seaward looking towards the light and clockwise. Many of our lights located along dangerous coastlines such as the Florida Keys have red and white sectors; when in the white sector the ship is usually in safe water but when in the red sector the ship is inside of a danger bearing and is in danger of running upon a reef.

719. BEARING BOOK

It is good practice to maintain a small book of convenient size for the recording of bearings and other desired piloting information, together with the identity of aids used and the time. Normally, the pages of such a record book are ruled so as to provide approximately six vertical columns. Each page, as used, is dated, and the first column on the left is used for the recording of time. In other columns, headed individually by the identity of aids, the bearings observed are accurately recorded, horizontally opposite to the recorded time. One column may be set aside for recording soundings for correlation with fixes as obtained. Bearings are true unless otherwise noted. If gyro bearings are recorded in lieu of true bearings, they must be so identified, together with the gyro error, if any. Because of the importance of such a record, as of other records having legal significance, erasures are not permissible. (See fig. 7-8.)

CHAPTER 8

BASIC ELECTRONIC NAVIGATION SYSTEMS

801. GENERAL

Electronic navigation is considered here as a definite division of navigation and one which will be further developed during the next few decades. As far as basic techniques are concerned, electronic navigation is an extension of piloting. It differs from piloting in the methods by which the data is collected.

Radio, radio direction finder, radar, sonar, loran and Decca, are examples of basic electronic navigation equipment. Radio, as used principally for obtaining time signals, weather, and hydrographic information, was briefly mentioned in art. 307. The other basic electronic instruments, together with related equipment such as radar beacons and Shoran, are addressed in greater detail in this chapter. More advanced electronic navigation systems are described in chapter 9.

802. MARINE RADIOBEACONS

Marine radiobeacons are important aids to electronic navigation and are described in H.O. 117 Radio Navigational Aids. The letters "RBn" denote their location on a nautical chart. They are particularly useful in piloting during periods of poor visibility. Transmitting in the medium frequency range, and identified by the dot and dash arrangement of their transmission, radiobeacons may be classified as directional, rotational, and circular. Directional radiobeacons simply transmit their signals in beams along a fixed bearing. Rotational radiobeacons revolve a beam of radio waves in a manner similar to the revolving beam of light of certain lighthouses. Circular radiobeacons, the most common type, send out waves in all directions for ship reception by radio direction finder as described in the following article.

803. RADIO DIRECTION FINDER

This is an azimuthal instrument, formerly called a radio compass, which upon receipt of a radio signal can determine the direction of the sending station. It is an important navigational aid because of its usefulness in search and rescue, or distress operations, and in homing aircraft.

Generally, the shipboard equipment consists of a receiver and two antennas. One antenna is a vertical stationary sense antenna, the other a rotatable loop antenna. The latter, in essence, is the "direction finder."

As the antenna is rotated, its output varies with the angle relative to the direction of the received signal. When it is perpendicular to the signal, signal strength is at a minimum or "null." The reading is taken at this point because a small change in the relative direction of the signal thus obtained causes a greater change in signal strength than does an equal change when the signal strength is at or near the maximum level.

Changes in the signal strength can be observed and related to bearings which are read from a dial. Bearings may be true or relative, depending upon the equipment. Since there are two "null" points for each complete revolution of the antenna, the sensing antenna works in conjunction with the loop antenna to resolve the ambiguity.

Variations of this antenna arrangement exist in the Automatic Direction Finder (ADF) in which two loops are rigidly mounted in such a manner that one is rotated 90° with respect to the other. The relative output of the two antennas is related to the orientation of each with respect to the direction of travel of the radio wave. Newer radio direction finders, often small, portable, and battery operated, have a ferrite rod coupled inductively to the receiver which serves in lieu of the loop antenna.

Radio bearings may be obtained from equipment other than the radio direction finder and if

the source of the signal can be identified, such bearings may be used to establish or to confirm a navigational position. As primary sources, however, marine radio beacons and direction finder stations are regularly provided in many parts of the world. Their position can be determined from maritime charts and from HO Pub 117, Radio Navigational Aids. It is of the greatest importance in plotting radio bearings to keep in mind the fact that the reciprocal of the bearing represents the direction of the ship from the transmitting source. These bearings are great circle bearings and over long distances must be corrected, prior to plotting on a Mercator chart, by a method described in HO Pub 117, Radio Navigational Aids.

804. RADAR

The word "radar" is an abbreviation for "radio detection and ranging." Radar equipment generates a directional radio wave which travels at the speed of light and which upon striking an object, is reflected back at the same velocity. A radar set is so calibrated that the range (distance) of an object can be directly read; this is feasible since the equipment is designed to compute distance from speed and time (the fraction of a second required for the signal to travel to an object and return is divided by two). The direction of a generated signal depends upon the direction the antenna is trained; for continuous search in all directions the antenna is permitted to rotate at uniform speed.

The principal parts of a radar set and their functions are:

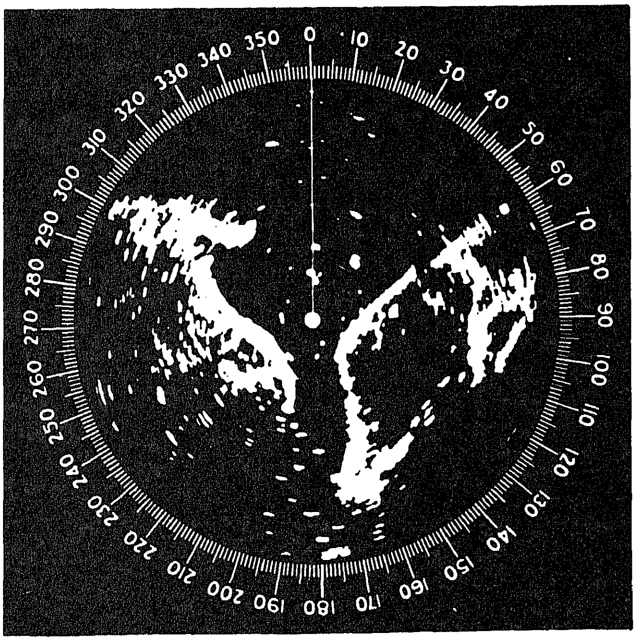
(a) Transmitter—Transmits electrical energy.
(b) Modulator—Cuts off transmitter periodically to convert signal to pulses.
(c) Antenna—Radiates signal and receives echo.
(d) Receiver—Receives echo via antenna.
(e) Indicator—Indicates the time interval between pulse transmission and pulse return as a measurement of distance to the reflecting object.

Part of the indicator is the cathode ray tube, the face of which is referred to as the "scope." There are two general types of scopes differing in presentation, the most common of which is the "PPI" or "plan position indicator." It is graduated in degrees for the direct reading of true and relative bearings; true direction is supplied by an input from the gyrocompass. The center of the PPI scope represents the ship's position. Reflecting objects within range appear as shapes upon the scope. Range may be read from the PPI scope either approximately by the use of concentric range circles or more accurately by matching a "range bug" with a target pip and reading the range from a dial. (See fig. 8-1.)

805. ADVANTAGES AND LIMITATIONS OF RADAR

The usefulness of radar, a range-bearing device, is illustrated by the following advantages:

(a) Safety in fog piloting—Radar provides an extra pair of eyes when the ship operates in reduced visibility, and can penetrate darkness and fog in the interest of safety.
(b) Means of obtaining range and bearing—This information may be sufficient to establish a fix.
(c) Means for rapidly obtaining fixes—The radar may easily provide position information faster than can be obtained through any other means. The PPI actually provides a continuous fix.
(d) Accuracy—This depends upon skill of the operator and the adjustment of the equipment;



190.12X
Figure 8-1—Radar PPI presentation.

however, an accuracy of a few yards may be attained.

(e) Range — The range is much greater than visual range. It depends upon the earth's curvature, as in the case of the radius of visibility of lights, and upon the characteristics of the set. It is not unusual to detect a high mountain at a range of 150 miles. The calculated distance to the moon was checked by radar, considerably prior to the making of lunar flights.

(f) Use as an anticollision device — The radar supplies information about the movements of nearby ships. Conning of the ship may be accomplished by reference to the PPI scope.

(g) Storm tracking — Radar is useful in tracking violent storms.

(h) Remote indication — The PPI scope presentation may be automatically indicated at remote locations.

The limitations of radar are:

(a) Mechanical and electrical character — It is subject to mechanical and/or electrical failure.

(b) Minimum and maximum range limitations — There is a minimum range limitation resulting from the echo of signals from nearby wave crests. These echoes are called "sea return." The radius of the sea return is a few hundred yards depending upon the adjustment of the equipment. Nearby objects may be obscured by the sea return thus establishing a minimum range. As previously mentioned, the maximum range depends upon the earth's curvature and the characteristics of the set.

(c) Interpretation — This is often difficult. The operator should be able to provide navigational information through the recognition of electron patterns. There is not always enough information for definite scope interpretation.

(d) Bearing inaccuracy — The radio waves travel as fan-shaped beams which result in echoes greater in width by several degrees than the angle subtended by the reflecting surface. If the beam width in degrees is known, the operator should add half the width to left tangents and subtract half the width from right tangents.

(e) Susceptibility to interference — Both natural (atmospheric) and artificial (jamming) interference may restrict usefulness of equipment.

(f) Necessity for transmission from the ship — This reduces security by breaking radio silence.

(g) Land shadows and sea return — These may cause objects not to be detected. Land shadows result when the land contour prevents radio waves from striking the entire surface. (A small hill in the rear of a high hill would appear in land shadow.)

806. ACCURACY OF RADAR

The accuracy of a radar position may be affected by the following:

(a) Beam width (bearing accuracy) — If visual bearings are available they should be used in lieu of radar bearings.

(b) Pulse length (range accuracy) — Range accuracy is usually greater than bearing accuracy.

(c) Mechanical adjustment.

(d) Ability of the operator.

(e) False targets — An example of a false target is surf which may reflect echoes and appear as a shore line.

(f) Shadows — This result of contours makes identification difficult as shapes on the scope may not correspond to actual shapes on the chart.

807. RADAR FIXES

The following methods, which are used in piloting, may be employed to establish a radar fix:

(a) Range and bearing of an object — The accuracy may be improved by the substitution of a visual bearing.

(b) Two or more bearings — Because of bearing inaccuracy this is not a preferred method.

(c) Two bearings and a range — If the range arc does not pass through the point of intersection of the bearings, the fix should be established as the point on the distance (range) arc equidistant from each bearing line.

(d) Two or more range arcs — This provides the best fix. Three arcs are better than two. Two circles may intersect at two points and thus force the navigator to choose between two possible positions.

(e) Three-arm protractor method — One may measure bearings of three objects and set up 3-arm protractor as described in art. 310.

808. VIRTUAL PPI REFLECTOSCOPE (VPR)

The VPR is an attachment which may be used in conjunction with the PPI scope of a radar to fix the position of the ship continuously on a navigation chart. It consists of a chart board upon which a navigation chart is secured, and a set of reflecting mirrors which serve to

reflect the chart upon the PPI scope. The center of the PPI scope represents the position of the ship; therefore, if the reflected chart image is matched with the scope, the center of the scope marks the ship's position on the chart. VPR charts must be drawn to a scale which is consistent with the range scale of the PPI scope. Sometimes the VPR chart is a grid chart thus enabling the operator to read at any time the grid position of the ship. The navigator may transfer this position to a navigation grid chart characterized by the same grid system but not necessarily having the same scale.

809. RADAR BEACONS

Two common radar beacons are "racon" and "ramark." RACON, used primarily in aircraft, consists of a transmitter and a receiver on board the aircraft and a transponder at some designated position. The aircraft transmits a signal, which upon being received by the transponder, triggers the transponder and sends a signal back to the aircraft; this returning signal is received upon a scope similar to a PPI scope. Direction can be determined since the signal appears as a radial line of dots and dashes extending from the center of the scope to the spot which represents the beacon. The periphery of the scope is graduated in degrees, so the bearings can be easily read. The length of the line determines range. The dots and dashes, identify the transponder.

RAMARK, designed primarily for marine use, is a beacon which transmits signals continuously. These signals when received, also appear as a radial line emanating from the center of a scope graduated to permit the reading of direction. The range can not be determined, and there is no coding system for identification.

810. TACAN

The word "TACAN" is an abbreviation for "tactical air navigation." It, like radar, is a range-bearing navigation system. Operating in the ultra high frequency portion of the spectrum, TACAN is designed to provide a continuous bearing and distance to a ground station. TACAN stations are identified by transmissions in International Morse Code at 35 second intervals. TACAN as a system is superior to earlier very high frequency omni-directional range and distance measuring equipment used in air navigation because it is more accurate and easier to operate.

TACAN is installed in military aircraft, and in some aircraft carriers as a homing device. It is operated simply by turning on a power switch, selecting a station, and reading the range and bearing. Maximum range is 195 nautical miles, and thus it is a short-range system. TACAN has been accepted as the primary navigation aid for the Air Route Traffic Control System.

811. SHORAN

"Shoran" is an abbreviation for "short range navigation" and makes use of the principle that radar ranges are more accurate than radar bearings. Signals from either a ship or aircraft trigger two fixed transmitters which send out signals simultaneously. The intersection of two circles of position on the receiving scope is representative of the ship's position. These circles may be drawn on the chart using the transmitters as centers. Shoran, a circular close range navigation system, may give an accuracy as great as 25 feet but can accommodate only one ship or aircraft at a time and is limited in range by the curvature of the earth.

812. SONAR

"Sonar," an abbreviation for "Sound navigation ranging," operates in principle as the fathometer or echo sounder as described in art. 306 except that it radiates a signal which is generally horizontal rather than vertical. Accurate ranges on underwater objects may be obtained, and inasmuch as the sonar transducer can be rotated, reasonably accurate bearings may also be obtained. Using such ranges and bearings, or ranges alone, piloting procedures as also applicable to radar are used. In fog or other reduced visibility, the sonar may provide the most accurate and useful information, particularly if rock ledges are present. The sonar is also most helpful in detecting and avoiding ice bergs.

813. LORAN

"Loran," an abbreviation for "long range navigation," is a hyperbolic navigation system, developed in the Radiation Laboratories at Massachusetts Institute of Technology during World War II. It makes use of a cathode ray tube and electronic circuits to measure the time difference between receipt of two signals traveling at the speed of light (about 186,281 miles per second). Loran-A is standard loran. Another type of loran,

loran-C, is described later in this chapter. In contrast with radar, loran is characterized by:

(a) Having on board a ship or aircraft a receiver but not a transmitter (radar both transmits and receives).

(b) Measuring the time difference in receipt of two signals instead of measuring the time required for an outgoing signal to travel to a reflecting surface and return.

(c) Utilizing low frequencies (1750-1950 kHz in loran-A and 90-110 kHz in loran-C) while radar utilizes high frequencies.

(d) Requiring ground stations to transmit signals as pulse emissions. Radar requires no other station; it is complete in itself.

814. THEORY OF LORAN-A OPERATION

Loran-A operating stations (transmitting stations) are organized in pairs called "station pairs." The station pair consists of a master or key station and a secondary station; the two stations, on the average, are located 200 to 400 miles apart. Each station sends out synchronized pulses at regular intervals and the receipt of signals from a station pair by a ship or an aircraft makes it possible to read the time difference. The ship's line of position, based upon one time difference reading, is a hyperbolic line since such a curve defines all points a constant difference in distance from two fixes points (in this case from two transmitting stations). Time difference readings are measured in microseconds; a microsecond equals one millionth of a second, and is abbreviated "ms."

The arc of a great circle which connects two stations of a station pair is the baseline. The perpendicular bisector of the baseline is the centerline. Extensions of the baseline are simply called baseline extensions.

Loran-A equipment aboard ship consists of a receiver-indicator (fig. 8-2). The receiver picks up and amplifies a signal while the indicator provides a video presentation. The indicator also contains a timer by which the navigator can measure the interval in microseconds between times of receipt of pulse emissions from a given pair of stations.

Station pairs are identified by frequency (channel), basic pulse recurrence rate, and specific pulse recurrence rate. There are four channels expressed in kilo Hertz (khz), with frequencies as follows:

Channel 1 1950 kHz.	Channel 3 1900 kHz.
Channel 2 1850 kHz.	Channel 4 1750 kHz.

There are three basic pulse recurrence rates associated with each channel:

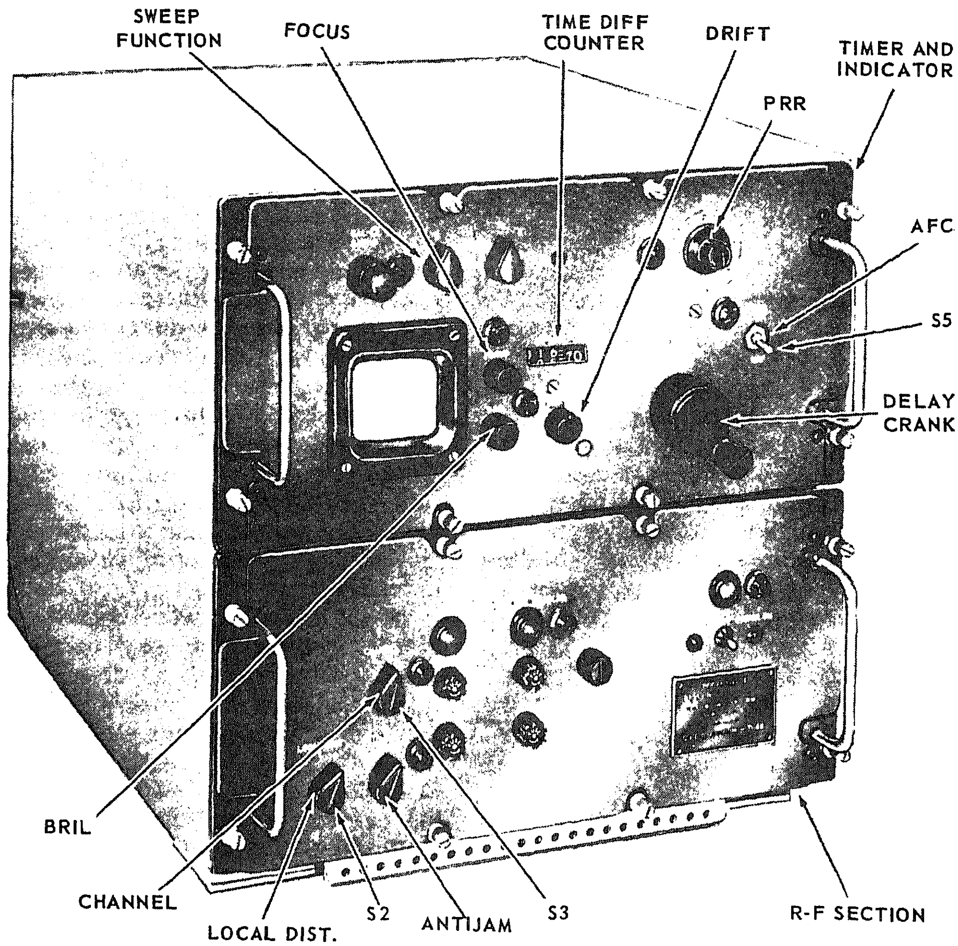
S—Special—20 pulses per second with 50,000 ms intervals

L—Low—25 pulses per second with 40,000 ms intervals.

H—High—33 1/3 pulses per second with 30,000 ms intervals.

The interval is the quotient when one million is divided by the number of pulses per second. There are eight station pairs, numbered from 0 to 7, associated with each basic pulse recurrence rate, each station pair having a specific pulse recurrence rate. In the case of station pair 0, the specific pulse recurrence rate equals the basic pulse recurrence rate. Other station pairs have a specific pulse recurrence rate less than the basic pulse recurrence rate and differing by a value equivalent to 100 ms times the station pair number. Examples of specific pulse recurrence rates are as follows:

Station	Special BPRR	Low BPRR	High BPRR
Pair	Interval	Interval	Interval
0	50,000 ms	40,000 ms	30,000 ms
1	49,900 ms	39,900 ms	29,900 ms
2	49,800 ms	39,800 ms	29,800 ms
3	49,700 ms	39,700 ms	29,700 ms



69.47
Figure 8-2.—Loran-A receiver-indicator.

Station pairs are identified by number, a letter, and a number such as "1H2" which signifies channel 1, high basic pulse recurrence rate, and station pair No. 2 (specific pulse recurrence rate: 29,800 ms intervals).

The simplest receiver would present electrons in a horizontal line with two pips a distance apart equal to the time difference. However, receiver scopes are designed having two traces, the upper or "A" trace and the lower or "B" trace. The B trace is actually the right hand half of a single trace presentation. By moving the pip on the lower trace, which is a signal from a secondary station, until it is directly beneath the signal from the master station on the A trace, we measure the time difference in microseconds.

In actual operation of the transmitting stations, three delays are introduced at the secondary station called (1) baseline delay, (2) half pulse recurrence rate delay, and (3) coding delay. The master station initiates a pulse which travels all directions (including along the baseline). This pulse, upon arrival at the secondary station, triggers the secondary transmitter. The delay thus introduced, the baseline delay, depends upon the speed of radio waves (speed of light) and the distance traveled, and is equal to the product of 6.18 ms and the length of the baseline in nautical miles; it insures that the master station signal will be received first. Upon receipt of a master signal by the secondary station, the half pulse recurrence rate delay is introduced, which is

the specific pulse recurrence rate interval in microseconds divided by two. This insures that one signal will appear on each trace, since the right half of the actual trace is underneath the left half and each half is equal to half the pulse recurrence rate. Last of all, the coding delay (950-1000 ms) is introduced; this provides a minimum reading and insures the operator of being able to determine which pip is to the right on the scope. The coding delay also provides security to the system in wartime, as it may be used to restrict the successful use of our loran-A stations.

To illustrate the relationship between the time difference reading and the observer's position, it may be helpful to examine the method by which a time difference reading can be predicted if the ship's position is known. In this example, the master station is 350 miles from the secondary station. The ship is located 400 miles from the master station and 200 miles from the secondary station. The coding delay is 1000 ms. The signal will travel from the master station to the ship in a time interval equal to 400 miles x 6.18 ms per mile or 2472 ms. At the same time, the same signal will travel along the baseline to the secondary station. The period of time which elapses during the travel of a pulse to the secondary station is dependent upon the length of the baseline and in this case is equal to 350 miles x 6.18 ms per mile or 2163 ms. Upon the arrival of the master station pulse at the secondary station, the secondary station is actuated, but before transmitting, it introduces first the half pulse recurrence rate delay and secondly the coding delay. It is not necessary that we know the value of the half pulse recurrence rate delay because our scope is so constructed that the half pulse recurrence rate delay does not enter into the measurement. Since the trace is divided into an A trace and a B trace, and since the lower pip is moved underneath the upper pip, the chief separation or half pulse recurrence rate delay cancels itself out. The lower pip is not moved as far as would be necessary if the scope contained a single trace, and this distance which it does not travel is the half pulse recurrence rate delay which ensures that one pip will appear on each trace. The coding delay is 1000 ms and this value will be measured by the loran receiver. At the end of coding delay, the secondary station will transmit, and the time required for the receipt of this transmission is 200 miles x 6.18 ms per mile or 1236 ms. Adding 2163 ms (baseline delay), 1000 ms (coding delay), and 1236 ms (time of travel of signal from secondary station to ship), the sum is 4399 ms. Subtracting 2472 ms from 4399 ms we find the predicted time difference to be 1927 ms, which identifies a hyperbolic line of position.

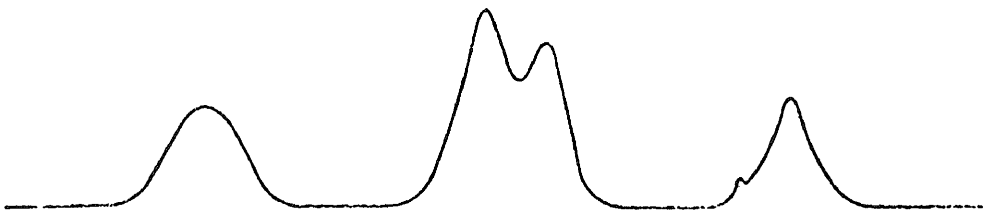
Sometimes a master station will be located between two secondary stations and will transmit on two frequencies or recurrence rates in order to key (control) two secondary stations. This is called "double pulsing."

The accuracy of loran-A depends upon a ship's position with respect to the baseline. On the baseline, the greatest accuracy is experienced, as one microsecond may represent only 250 yards. Proceeding away from the baseline along the centerline, accuracy gradually decreases. Along the baseline extension, one microsecond may represent as much as 10 miles, and a fix obtained in this area may be inaccurate. If one microsecond represents more than 2 nautical miles, the loran can not be expected to give satisfactory results in navigation.

Two types of waves are used in loran-A, ground waves and sky waves. Ground waves are those which travel directly from the transmitting station to the ship and have a maximum range limitation under average conditions of 700 miles. Sky waves reflect from the ionosphere (ionized layers of atmosphere) and arrive after ground waves because of the greater distance traveled. For identification, the first sky wave reflected from the "E" layer of the ionosphere is known as the "one hop E," and the second as the "two hop E." The first sky wave to be reflected from the "F" layer accordingly is the "one hop F" and the second is the "two hop F." Sky waves have range limitations normally of 500 to 1400 miles. Five hundred and seven hundred miles mark the lower and upper boundaries of the critical range, inside of which wave identification is necessary. In matching pips, a ground wave from the secondary station is matched to the ground wave from the master station or a first sky wave is matched to a first sky wave. Only "one hop E" sky waves are used. Second sky waves are not dependable, and sky waves are not matched with ground waves. See fig. 8-3.

815. LORAN-A INTERFERENCE

Loran-A interference differs from most other interference in that it is visual, rather than audible as in the case of radio and sonar. Atmospheric interference makes the flow of electrons uneven on the scope; this interference is



190.13X
Figure 8-3.—Scope appearance of waves.

descriptively called "grass." Radar transmissions appear as evenly spaced pips on a loran trace; electrical influences and code sending also produce visual interference. Fortunately, most interference does not impair scope reading.

Additional signals known as spillover and ghost pulses may interfere. Spillover is the term used to describe signals received from adjacent frequencies; since some channels are only separated by 50 kHz it is as possible to receive signals from two stations on a loran receiver as on a radio receiver. If a signal is suspected to be spillover, the set should be tuned to an adjacent channel or frequency. If it is spillover, the signal will come in stronger; if not it will fade. Ghost pulses may be received from an adjacent basic recurrence rate. Ghost pulses are characterized by their instability.

When a loran-A station is out of synchronization the signals either appear and disappear or appear to shift to the right about 1000 ms then back, at intervals of approximately 1 second. Such blinking action warns the operator not to take readings. When the stations are again synchronized, which usually requires not more than a minute, blinking ceases.

816. ADVANTAGES AND LIMITATIONS OF LORAN-A

The advantages of loran-A include the following:

(a) Speedy fixes (1-5 minutes).
(b) Rapidly trained operators (4 days at fleet schools).
(c) Weather does not affect reliability of operation.
(d) 24 hour service.
(e) Long range (1400 miles).
(f) Land does not reduce accuracy (of particular interest to air navigators).
(g) Fix is independent of accurate time.
(h) Homing is convenient.
(i) Radio silence is maintained.
(j) Jamming is difficult.
(k) Possible wartime security.

Disadvantages or limitations include:

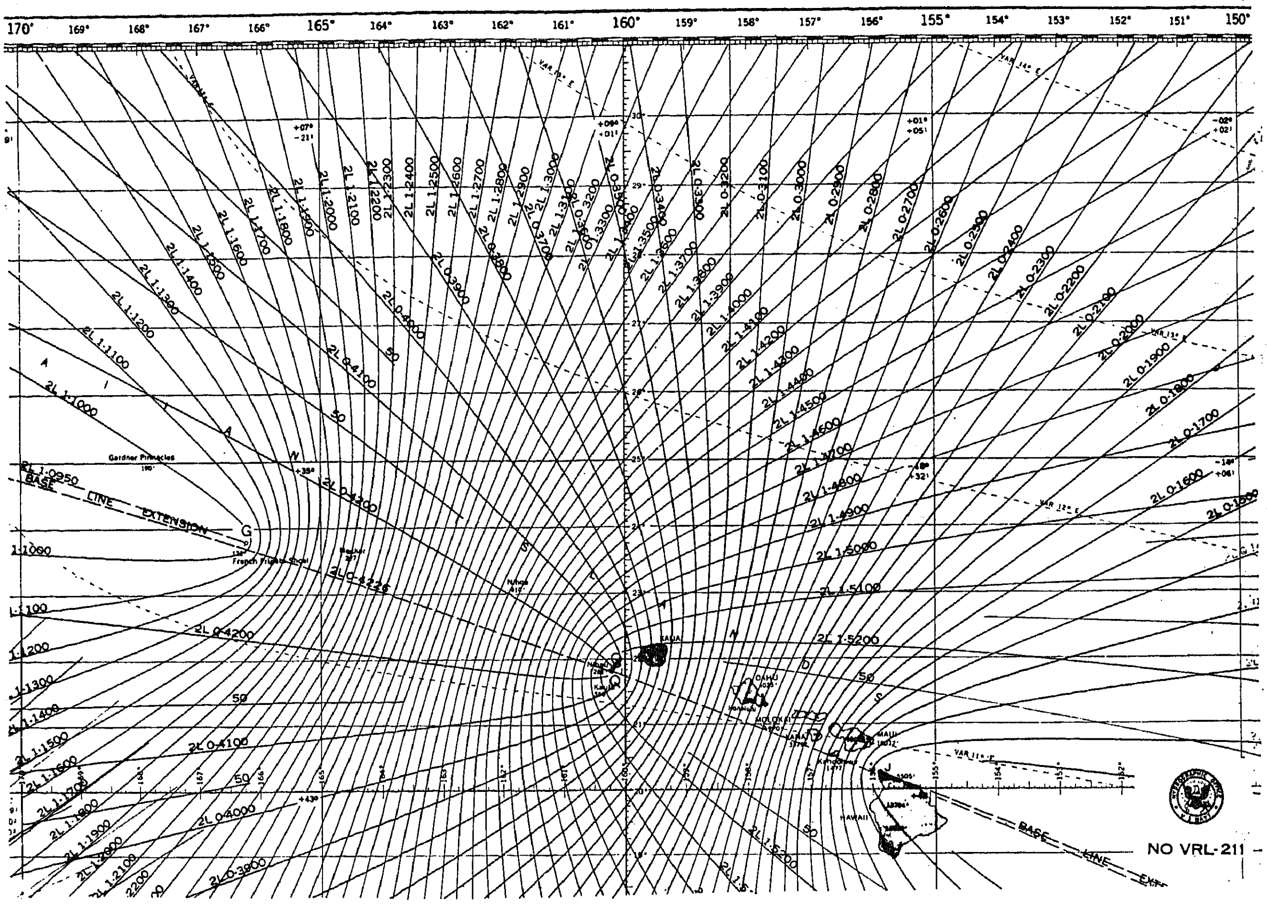
(a) Possible mechanical or electrical failure.
(b) Restricted coverage (lack of sites for transmitter stations, the expense of stations, and the need for agreements with foreign states).
(c) Identification of signals not always reliable.

817. LORAN-A CHARTS

Either loran-A charts (fig. 8-4), which are nautical charts over-printed with loran information, or loran-A tables (H.O. Pub. 221) may be used for converting loran-A readings into LOP's and fixes. Loran-A charts as normally available offer a rapid means, and have been made for those areas where loran-A signals are available.

Loran-A charts show hyperbolic lines of position usually for each 20 ms of time difference on large scale charts and for each 100 ms of time difference on small scale charts. The lines emanating from different station pairs are identified by their color as well as by a label of rate and ms time difference along each such hyperbolic line.

Charted hyperbolic lines are for ground wave time differences; if first sky waves are matched, then the time difference obtained must be corrected so as to be comparable to ground wave time differences. Corrections are found at the intersections of meridians and parallels and are



69.49

Figure 8-4.—A portion of a loran chart.

printed the same color as the rate to which they apply. Eye interpolation may be necessary to determine the sky wave correction, when the position of the ship is between tabulated values. When obtained, corrections are added or subtracted according to sign.

When plotting a loran-A fix, select two hyperbolic lines in the vicinity of the DR position between the values of which the actual time difference reading of a station pair lies. Using eye interpolation and a straight edge, draw a short line labeling it with the time above and the station pair number and ms time difference below. This is a loran-A line of position. By plotting two or more such LOP's (assuming they are obtained in rapid succession) a fix is obtained which is represented by a small circle and the time in four digits followed by the word "fix." If the LOP's are not obtained in rapid succession, then they should be advanced or retarded to a common time using procedures described in the study of the running fix. If the charted hyperbolic lines are far apart, a self-explanatory linear interpolater appearing on loran charts may be used to increase the accuracy and lessen the difficulty of interpolation.

The accuracy of a loran-A fix depends upon the angle of intersection of LOP's, the position with respect to the transmitting stations, the synchronization of the station pair, and the operator's skill in identifying and matching signals.

818. LORAN-A OPERATION

The steps in taking and using a loran-A reading in the AN/UPN-12 and similar sets, are normally as follows:

(a) Determine from the approximate position of the ship, the transmitting station pairs which

serve the ship's position,and the type of signals expected from these transmitting station pairs.

(b) Turn on the receiving set by setting the power switch to the "standby" position.

(c) Allow a warm-up of at least one (1) minute before switching to "power-on." Turn the power switch to "power on" position.

(d) Refer to the Loran-A Charts of the approximate geographical location of the ship. Set the "pulse recurrence rate" (PRR) and "channel" to correspond to a loran-A transmitting station pair determined in Step 1. Set "sweep function" switch to one, the AFC switch to "off" and the "time difference" counter to approximately 11,000 with "delay" crank.

(e) Adjust the "gain" and "bal" controls to equalize signal heights. Set "Local-dist" switch to D, I, or L, dependent upon which position will obtain best operating conditions.

(f) Use "drift," "gain," "bal," and "L-R" controls to locate the desired signals, then turn the "drift" control to a point where the signals are locked in on the indicator screen. Readjust the "gain" and "bal" controls so that signals are of convenient operating amplitude.

(g) Determine ground and sky-wave components of the signals and decide whether ground or sky-wave matching is to be used.

(h) Use the "L-R" switch to position the upper (master) pulse selected for matching at the leading (left) edge of the upper pedestal.

(i) Set the "AFC" switch to the "on" position. Unless noise pulses cause pulse jitter, leave the "AFC" switch in this position for the remainder of the following procedures and leave the "antijam" switch in the "out" position. If heavy interference is encountered, leave the "AFC" switch off and set "antijam" switch to the "in" position.

(j) Use the "delay" crank in the "coarse" position to place the leading edge of the lower pedestal under the lower (secondary) pulse which corresponds to the selected master pulse.

(k) Set the "sweep function" switch to position 2.

(l) With the "delay" crank in the "fine" position, align the two selected pulses vertically.

(m) Set the "sweep function" switch to position 3.

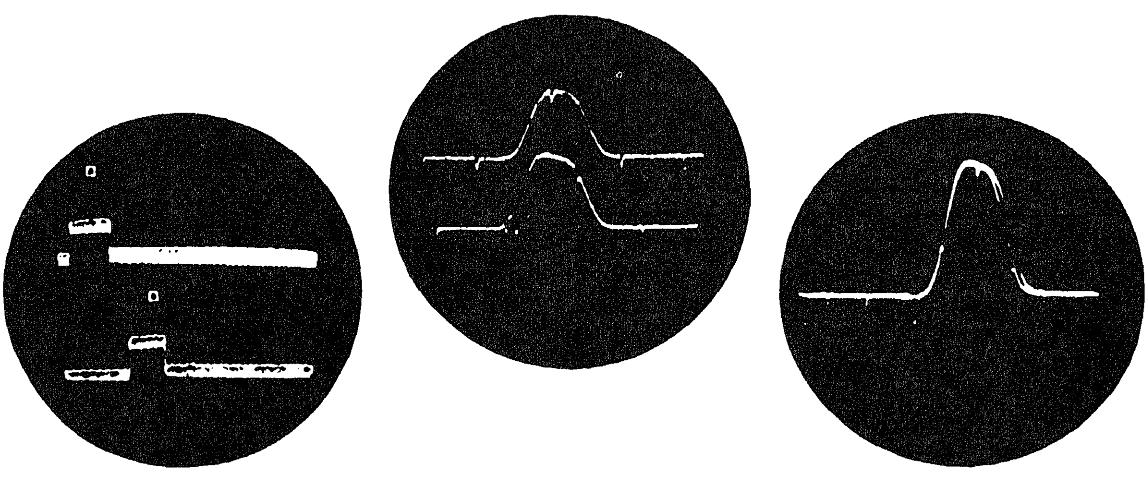
(n) Match the two pulses, using the "delay" crank (in the "fine" position) "gain" and "bal" controls. (See fig. 8-5.)

(o) Record the "time difference" counter-reading.

(p) Repeat steps d through o, setting the "PRR" and "channel" switches to the pulse recurrence rate and channel corresponding to the others of the loran-A transmitting pairs.

(q) Apply necessary corrections to the "difference" readings, referring to Loran-A navigation tables or charts. Take into account the time of day at which readings were taken, whether received signals were strong or weak, and whether ground or sky waves were used to match signals. Plot lines of position.

(r) Obtain loran-A fix, considering the relative accuracy of the various lines of position which depend, among other things, on the spacing



70.99(190)X
Figure 8-5. — Matching Loran-A signals.

of the lines of position in the geographical area of the ship.

(s) Compare the loran-A fix with other navigational information, and make the necessary record entries of the exact location of the ship.

(t) Turn the "power" switch to the "standby" or "off" position.

819. LORAN-C

Loran-C is a pulsed, hyperbolic, long-range navigation system, operating on a radio frequency of 90-110 kHz. It was developed for greater range and accuracy, and first became operational in 1957. Because of its lower frequency, and greater baseline distance (500 to 700 miles as compared to 200 to 400 miles in Loran-A), reasonable accuracy to 1200 nautical miles for ground waves and 3000 nautical miles for sky waves can be attained. Basic principles of operation are similar to those which apply to Loran-A, however, greater convenience of operation is provided.

A Loran-C network consists of one master and two or more secondary stations. As in Loran-A, the signal from the master activates each secondary station. Network arrangements include (a) the triad, with a master between two secondaries; (b) the star or "Y" formation with a master positioned between three secondaries; and (c) the square. It should also be noted that a master station may serve as a secondary station in another network. Loran-C uses a multipulsed transmission with eight pulses each 1000 ms, except for signals from the master station, which include a ninth pulse for identification. Pulses are phase-coded, which protects against interference from outside sources and reduces the contamination of ground waves by sky waves. Loran-C receivers are specially designed; however, the system is sufficiently compatible with Loran-A that receivers in the latter system can be modified for Loran-C use, except for 12 specific pulse recurrence rates, but with less accuracy. Phase measurement, which is helpful in station identification and in discrimination between ground waves and sky waves, as well as most other operations with Loran-C receivers, is automatic; read-outs are direct. The constant time difference obtained from the reading on one station pair, as in Loran-A, provides a hyperbolic line of position.

A major difference between systems is that in Loran-C, all stations share the same radio frequency (RF) channel. There are six basic pulse recurrence rates as follows:

H	33 1/2	pulses/second
L	25	pulses/second
S	20	pulses/second
SH	16 2/3	pulses/second
SL	12 1/2	pulses/second
SS	10	pulses/second

Associated with each basic pulse recurrence rate are eight specific pulse recurrence rates. As in Loran-A, specific pulse recurrence rates are separated from the basic pulse recurrence rate by multiples of 100 ms. Station type designators consist of one or more letters to indicate the basic pulse recurrence rate (H, L, S, SH, SL, or SS), a number (0-7) to indicate the specific pulse recurrence rate, and letters such as X or Y to indicate a particular secondary station.

Ground wave coverage is a function of propagation strength, and the strength of signal to noise ratio. Ground waves may extend as far as 2000 nautical miles and are normally reliable to 1200 nautical miles for 300 KW pulse power. First hop-E sky waves extend out to 2300 miles, and second hop-E sky waves may reach out to 3400 miles. To be sufficiently stable for use, complete darkness is usually necessary for receipt of second hop-E sky waves. Accuracy of Loran-C pulse transmissions, as made possible by phase comparison and longer baselines, depends upon atmospheric conditions, noise and interference. Ground waves are normally accurate to 0.1 percent of the distance traveled. Sky wave accuracy is usually to 3 to 5 miles.

Plotting procedures in Loran-A and Loran-C are similar. A single observation provides readings which establish lines of positions for all pairs within a network. For maximum accuracy, Loran-C tables (H.O. Pub. 221 series) may be used. In those circumstances in which modified Loran-A equipment is used, because of elapsed time between readings, it may be advisable to advance or retard certain LOPs using running fix procedures.

Loran-C provides for (a) electronic navigation; (b) systemized long-range time distribution; (c) time standardization between widely separated receiving locations; and (d) the study of electromagnetic wave propagation.

820. DECCA

Decca is a low frequency British hyperbolic radio navigation system first used in World

War II to guide allied forces to the Normandy beaches. It is highly accurate and reliable, and like other electronic systems, its operation, although slightly affected by atmospheric conditions, is not precluded by low visibility. In this system, chains are established, with each chain consisting of one master and three secondary stations. Preferably, the secondary stations are equally spaced on a circle with a radius of 70 to 80 miles and with the master station at the center. Decca operates in the 70 to 130 kHz band.

Secondary stations are identified by the colors purple, red, and green. These, and the master, transmit a continuous wave at different frequencies. A hyperbolic line of position is determined by the phase relationship of a secondary signal as compared with the signal of the master. Two secondaries and a master provide readings from which a fix can be obtained. The third secondary in a chain serves as a check. Fixes are plotted on Decca charts showing hyperbolic lines in color corresponding to that of the associated secondary station. The Decca receiver consists of four radio receivers, one for each frequency. By the reading of dials called Decometers, the necessary information for plotting a fix is obtained.

Decca coverage is available over most of Western Europe, in parts of the Indian Ocean including the Persian Gulf, along the coasts of Eastern Canada and the Northeastern United States, and along the coast of Southern California. Its reliable operational range, accurate to about 150 yards in daytime and 800 yards at night, is approximately 250 miles. Decca receivers may be carried in aircraft as well as ships.

United States and Canadian rights to the Decca system are held by the Pacific Division of Bendix Aviation Corporation, which also produces a long-range companion of Decca called Dectra. Useful to both ships and aircraft, Dectra primarily serves transatlantic aviation.

CHAPTER 9

ADVANCED ELECTRONIC NAVIGATION SYSTEMS

901. GENERAL

Electronic navigation, essentially an extension of piloting, has been characterized since 1950 by a proliferation of systems. Basic electronic navigation devices, as developed and earlier accepted for general use, were described in Chapter 8. This chapter, while not addressing all of the many new devices and systems in use today, provides basic descriptive data for the newer and more sophisticated systems in use.

One method of classification of electronic navigation systems, based upon the form of the line of position or fix obtained, includes five types or categories as follows:

(a) Hyperbolic—Loran and Decca, and as described in this chapter, Omega and some types of Raydist.

(b) Circular—Shoran, and Raydist.

(c) Azimuthal—Radio direction finder, and as described herein, Consol and Consolan.

(d) Range-bearing—Radar and Tacan. This includes "Ratan," a limited form of radar navigation described in this chapter.

(e) Motion sensing—As described herein, Satellite Navigation (NAVSAT), Inertial Navigation, and Acoustic Doppler.

A second and equally as valid a method of classification is based upon range, as follows:

(a) Short-range—Radar (including Ratan) and Shoran.

(b) Mid-range—Raydist.

(c) Long-range—Radio direction finder, Decca, and Loran, and as described in this chapter, Consol, Consolan, Omega, Satellite Navigation (NAVSAT), Inertial Navigation and Acoustic Doppler.

902. RATAN

Currently undergoing consideration and in limited use is the Radar Television Aid to Navigation, called RATAN. It is simply an extension or a refinement to radar navigation making use of shore stations, high-definition radar, and UHF television equipment, to transmit a radar image. The receiver, an inexpensive transistorized television receiver, provides a display of the shore line, channel buoys, lighthouses, other markers, and moving ship traffic. Whereas radar shows a ship as the focal point on a radar scope, RATAN presents a fixed background with the ship moving within the pattern. An added feature is a scan coverter which stores the radar image and identifies moving objects on the screen. Moving vessels are identified on the scope by their "fading tails," an indication of relative movement.

RATAN is important because it is an all-weather navigation device and inexpensive, but has the disadvantage of being dependent upon a transmitting station ashore. Furthermore, on board reception has been poor, and needed frequencies have not yet been allocated. Assuming that reception can be improved and frequencies allocated, it is being considered as a possible adjunct to Marine Traffic System Installations.

903. RAYDIST

Raydist, through precise tracking of CW transmitters, is useful in navigation, surveying, and other position plotting. It is used extensively by the National Ocean Survey, commercial organizations such as those engaged in offshore oil exploration, and foreign governments. An early form of Raydist, Type E was used for tracking the first U.S. satellites.

Raydist is considered here as a mid-range navigation system. It employs radio distance measuring to produce either circular or hyperbolic lines of position; however, types of Raydist

earlier used to produce the latter are now gradually being replaced by circular distance measuring forms which are non-saturable and have greater potential for accuracy. An example of the newer forms is the Type N.

In operation, Raydist requires two CW transmitters on a baseline, with a separation of as much as 100 miles. Operating frequencies are in the 1.6 to 5 mHz range, permitting effective transmission beyond line of sight range. Depending upon power, ranges up to 200 miles may be reached. Stations differ by about 400 cycles per second, which permits phase comparison at other locations. An accuracy of one to three meters may be achieved.

Raydist equipment, including the transmitters, is generally small, compact, and light in weight. The equipment is fully automatic, providing a direct reading of phase comparison.

904. LORAN-D

This is a low-frequency, pulsed-type, semi-mobile, hyperbolic, navigation system. Being transportable, it can be moved to new areas and used as needed. The frequency range, as in Loran-C, is 90 to 110 kHz and signal characteristics are similar except that Loran-D uses groups of 16 pulses, repeated each 500 microseconds. The system is (a) highly accurate over a range of 500 miles using ground waves; (b) quite resistant to electronic jamming; (c) relatively mobile; and (d) equally useful in surface vessels and high speed aircraft.

905. CONSOL

Consol is a long-range, azimuthal, radio navigation aid. It was developed and used by the Germans (and known as SONNE) during World War II. It was later improved by the British. As a system, it can be considered as an improved version of the radio direction finder (RDF). An observer, using an ordinary receiver, interprets a pattern, and through either RDF or dead reckoning information, determines his sector of the pattern. Lines of position, with much greater accuracy than obtainable with RDF, are plotted on special charts. Maximum ranges reach 500 to 1400 nautical miles, generally with an LOP accuracy of a fraction of one degree. Minimum range is 25 to 50 nautical miles. It operates in a frequency range of 250 to 350 kHz.

Consol is highly reliable because of the simplicity of equipment. Consol transmitters, situated at consol shore stations, feed three antennas with energy of the proper phase and amplitude, thus generating the field pattern. The receiver is equipped with an omnidirectional antenna. Consol stations are located in Western Europe, ranging from southern Spain to the Soviet Arctic.

906. CONSOLAN

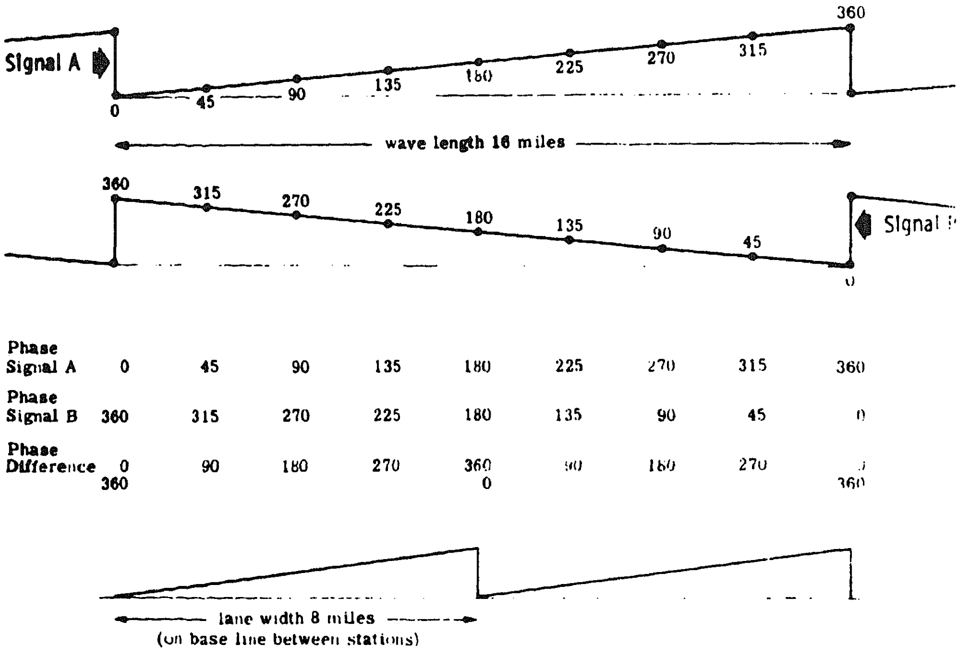
Consolan is an American version of Consol, and accordingly is a long-range, azimuthal navigation system. In contrast with Consol, Consolan uses two transmitting antennas rather than three. Consolan increases coverage by using higher power levels and lower frequencies (190 to 194 kHz). The pattern generated is the same as that provided by Consol. Special charts and tables are provided for use with Consolan, by the U.S. Naval Oceanographic Office. U.S. Consolan stations are located in San Francisco and Nantucket.

907. OMEGA

A new electronic, hyperbolic, navigational system, similar to Loran, is Omega. It is a long range, pulsed, phase-difference, very low frequency (VLF) system, operating on a frequency of 10 to 14 kHz. It is a worldwide, all-weather system, of use to ships, aircraft, and submarines, including submarines submerged. Its accuracy is about one mile during the day and two miles during the night. Phase difference measurements are made on continuous wave (CW) radio transmissions. Like Loran, shore transmitting stations are used. Theoretically, six such stations are required for worldwide coverage; however, two additional stations are required to provide a degree of redundancy necessary to accommodate station repair.

In the Omega system, the phase-difference measurement of a 10.2 kHz signal transmitted from two stations provides a hyperbolic line of position. At least one additional phase-difference measurement is required to establish a fix, and two or more are desirable. Unlike other hyperbolic navigation systems, any two stations from which signals can be received may be paired to produce a line of position. Special charts are provided by the U.S. Naval Oceanographic Office for Omega plotting.

Since the wavelength of a 10.2 kHz signal is approximately 16 miles, and phase readings repeat themselves twice within this distance (see figure 9-1), lanes eight miles in width are established. Thus each lane or band is the equivalent in distance of one half of a wave length. The



190.14X
Figure 9-1.—1.2 kHz phase-difference measurement.

actual phase-difference reading establishes the line of position within the lane.

To avoid ambiguity in lane identification, Omega stations transmit also on 13.6 kHz, a frequency having a wave length exactly one third shorter than 10.2 kHz. Every fourth contour of this frequency coincides with every third contour on 10.2 kHz, and thus one broad lane matches three narrow lanes obtained on the 10.2 frequency.

All Omega stations transmit on the same dual frequencies, at different times. Eight stations share a ten second time interval. The receiver (see figure 9-2) identifies each station by its place in the sequence and by the precise time duration of its signal.

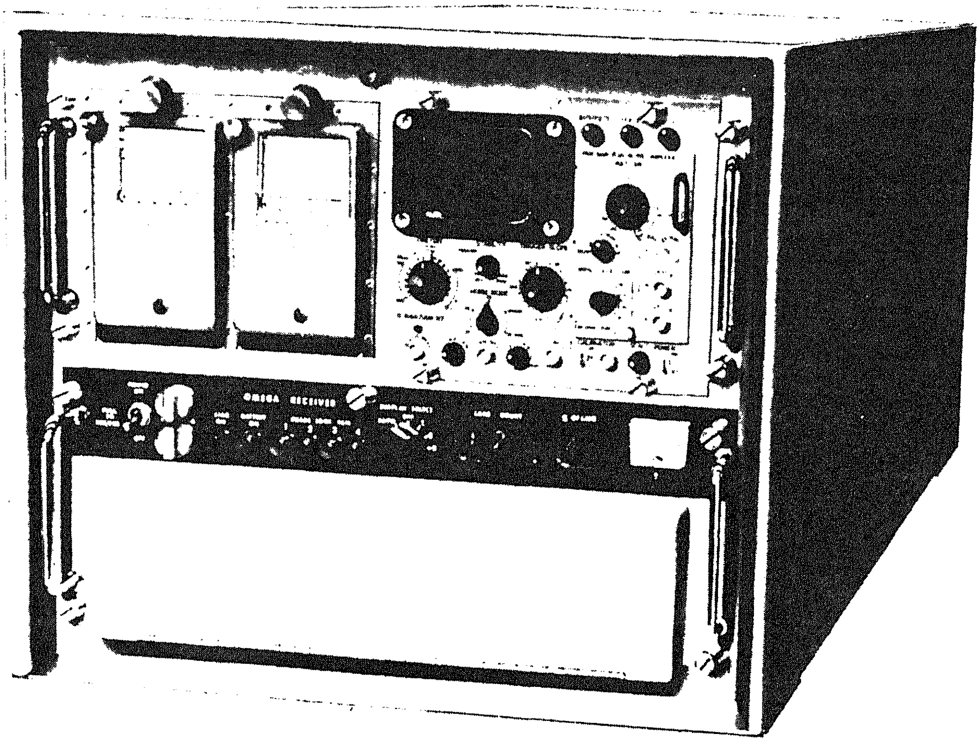
Long base lines of approximately 5000 nautical miles and sometimes as much as 6000 miles, are used. The system is serviceable to about 6000 miles. For greater accuracy of position, the navigator should consider the geometrical relationship and select station pairs yielding lines of position which will cross at angles of 60 to 90 degrees.

A technique known as differential Omega has been established to attain greater accuracy in a particular area. Two or more receivers are compared and the distance between them determined from the difference in their readings. For example, one may be located at a known position ashore and its reading continuously broadcast, for comparison with readings obtained by vessels nearby. In this manner, long distance propagation errors can be generally eliminated.

Omega was developed in the early 1960's by the U.S. Navy for use throughout the Defense Establishment and commercially. It is simple for the user to operate, accurate, and provides worldwide coverage. At some future time it is possible that Omega will replace Loran.

908. SATELLITE NAVIGATION (NAVSAT)

As Project Transit, the U.S. Navy developed a Navy Navigation Satellite System at the Applied Physics Laboratory of the John Hopkins University. In use since 1964, the system now known as "NAVSAT" provides for accurate, all weather, world-wide navigation of surface ships, submarines, and aircraft. The accuracy is exceptional, the navigational error normally not exceeding 200 yards. Although NAVSAT was developed initially for naval use, it has been available to commercial shipping since 1968.



120.48
Figure 9-2.—AN/SRN-12 Omega Shipboard Navigation Receiver.

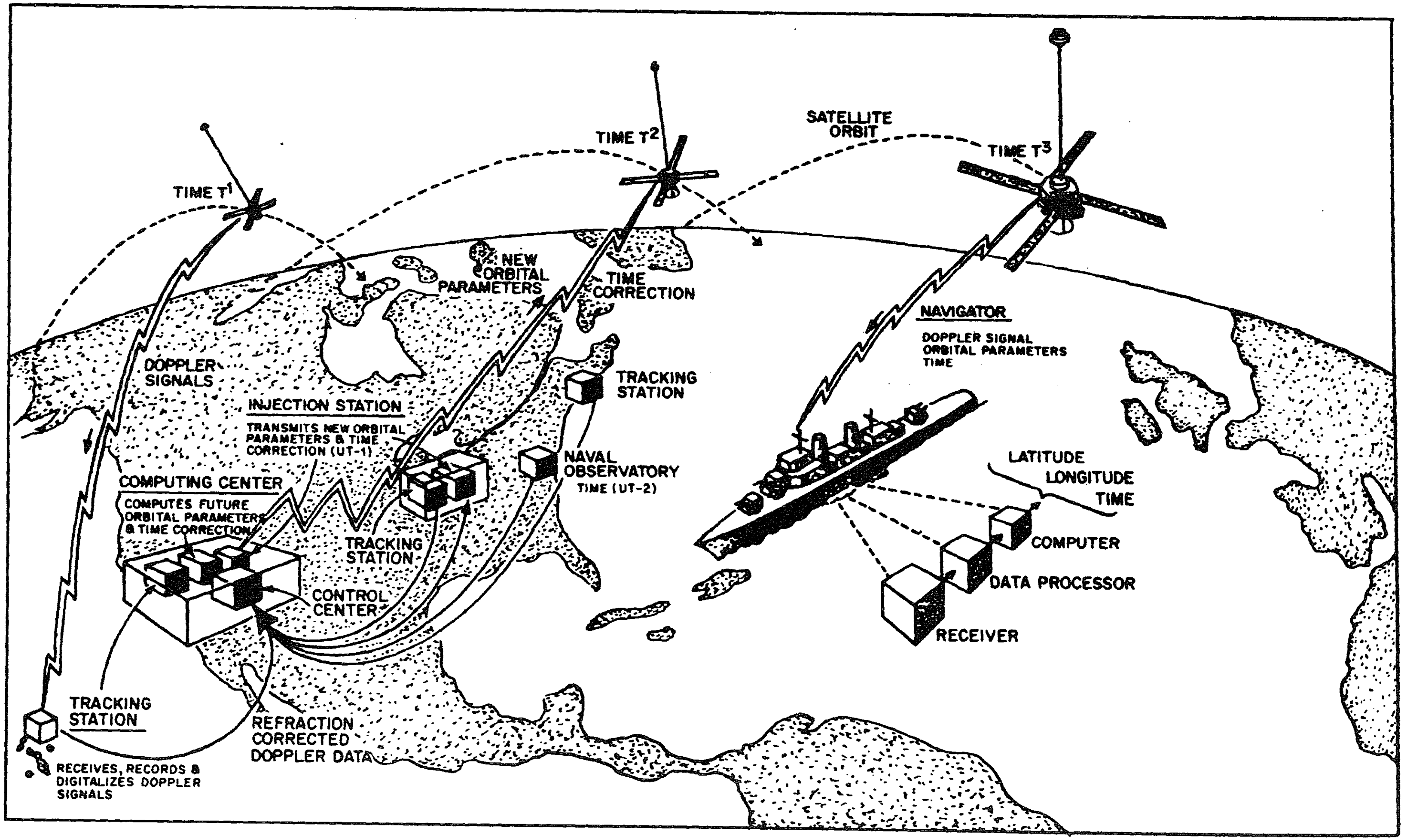
The operation of NAVSAT involves a phenomenon known as Doppler shift, which in radio waves is the apparent change in frequency when the distance between transmitter and receiver changes. Dependent upon relative motion, Doppler shift is proportional to the velocity of an approaching or receding NAVSAT satellite. With the approach, the frequency shifts upward; accordingly, with a satellite in recession, the frequency shifts downward. The Doppler shift actually experienced depends upon the position of the receiver with respect to the path of a transmitting satellite.

Components of the NAVSAT system include one or more satellites, ground tracking stations, a computing center, an injection station, accurate Greenwich mean or Universal time from the Naval Observatory, and the shipboard receiver and computer.

Each NAVSAT satellite travels in a polar orbit, at an altitude of approximately 600 nautical miles, circling the earth once each 105 minutes. The orbital planes of the satellites, while essentially fixed in space, intersect the earth's axis and make the satellites appear to be traversing the longitudinal meridians as the earth turns beneath them. The orbital planes are separated by approximately 45° of longitude. Only one satellite need be used to establish a position. Each satellite continuously broadcasts data giving the fixed and variable parameters which describe its own orbit, together with a time reference. Periodically, approximately every 12 hours, a ground injection station broadcasts to each satellite, updating the data stored and enabling the satellite to broadcast current information. This updating information passed by an injection station is obtained from a computing center at Point Mugu, California which receives orbital inputs from a ground tracking station, and time from the Naval Observatory. See figure 9-3.

Because of the effect of the ionosphere upon radio waves, NAVSAT satellites use two ultra high broadcast frequencies, 150 and 400 mHz. As each frequency is differently affected by the ionosphere, Doppler signals received can be compared and the effect determined. Allowance is then made in position calculations for the ionospheric effect.

Unlike a planet in space, which travels in an elliptical orbit in accordance with Newton's laws



162.58
Figure 9-3.—NAVSAT.

of motion (see Appendix B), a NAVSAT satellite operating at an approximate altitude of 600 nautical miles is affected by the shape of the earth and its irregular gravitational field. Since it is not operating in a complete vacuum, the satellite experiences some atmospheric drag. It is also affected by the gravitational attraction of the sun and moon, charged particles in space, and the earth's magnetic field. These disturbances to the Keplerian orbit are predictable and can be computer programmed.

Four satellite tracking stations monitor the Doppler signal of the satellites as a function of time. The Naval Observatory monitors the satellite time signal. Comparison information is passed to the computing center. NAVSAT users receive operational information of the satellites or "birds" through messages from the U.S. Naval Astronautics Group, Point Mugu, California.

Shipboard equipment consists of a receiver, a computer, and a tape read-out unit. The ship's estimated position and speed are required as local inputs to the shipboard equipment. The estimated position need not be accurate; however, accuracy of the speed input is essential. An inaccuracy of one knot in ship's speed may cause an error of 0.25 miles in a NAVSAT fix. Speed errors with a mainly north-south component cause a greater position error than speed errors largely with an east-west component. The shipboard equipment is quite sophisticated and requires expert maintenance.

A NAVSAT fix can be obtained when a passing satellite's observed maximum altitude is between 10° and 70°. NAVSAT is most convenient to use inasmuch as the tape readout unit provides the latitude and longitude of the ship's position in typewritten form. In addition to being a convenient, all-weather system, NAVSAT has proved to be extremely accurate and reliable.

909. INERTIAL NAVIGATION

Inertial navigation is essentially an improved form of dead reckoning in which velocity and position are determined through relatively accurate sensing of acceleration and direction. Inertial systems, used for long range navigation, are completely self contained, require no shore support, and are independent of weather.

The first known application of inertial navigation was in the guidance system of German V-2 rockets. Following World War II, the United States continued the development of inertial systems, with the first satisfactory system appearing in the early 1950's. U.S. models were first developed for use in aircraft, later were used in ballistic missiles and spacecraft, then widely used in Polaris submarines, and finally were accepted for general use in surface ships and attack submarines. The system used in the U.S. Navy is called the Ship's Inertial Navigation System (SINS), an early model of which was designed by the Massachusetts Institute of Technology and was installed by the Sperry Gyroscope Division of Sperry Rand Corporation in USS COMPASS ISLAND in 1956.

The inertial navigator through instrumentation measures the total acceleration vector of a vehicle in a gyroscope stabilized coordinate system. Integrating acceleration with time, and applying the computed components to initial velocities, makes it possible to determine actual velocity components and distances traveled. As in other forms of dead reckoning, any error, small though it may be, will with time contribute to a position error. Accordingly, using the systems approach, the position data is not only subjected to internal monitoring, but it is periodically corrected, based upon navigational information from external sources. For example, SINS can be associated with NAVSAT, sharing in some instances a SINS general purpose computer; the inertial position can be updated based upon satellite information.

The basic sensors used in inertial navigation are gyroscopes and accelerometers. Three gyroscopes are normally mounted on a platform as follows:

(a) Gyro "x" with its spin axis aligned in a North-South direction;

(b) Gyro "y" with its spin axis aligned in an East-West direction;

(c) Gyro "z" with its spin axis perpendicular to the "x" and "y" gyros.

The purposes of the "x" and "y" gyros are to sense roll and pitch of the ship, and through the use of torqueing motors, to keep the platform perpendicular to a line passing from the center of the platform to the center of the earth. The purpose of the "z" gyro is to supply heading. Thus the gyroscopes provide a stable platform and a direction reference.

Two accelerometers are used to establish acceleration in the North-South and the East-West directions. The accelerations and decelerations sensed by accelerometers are algebraically added to the speed stored in the computer, thereby continually updating the ship's speed. Such inputs in N-S and E-W components, are resolved by computor into actual or true speed. True speed and heading are continually used to update the ship's position, giving read-outs in latitude and longitude.

Since the force of gravity can be interpreted as an acceleration by the accelerometers, it is vital that the accelerometer platform be kept in the proper plane and that unusual gravitational anomalies, such as unusually large vertical land masses, be noted and compensated.

Advances in computer technology have made it possible to make quite complicated mathematical calculations which are essential to inertial navigation. Sophisticated instrumentation measures the progress of a vessel in a spatial direction. By mechanization of Newtonian Laws of Motion, this complex system can provide position coordinates and other related information. For example, SINS provides a continuous read-out of latitude, longitude, and ship's heading. For stabilization purposes, it provides data on roll, pitch, and velocity. It provides information on ship's motion to NAVSAT; without SINS, inputs for course and speed must be given to the NAVSAT computer by the gyrocompass and log respectively. Currently, various inertial systems are coming into use to meet expanding navigational and other guidance requirements.

910. ACOUSTIC DOPPLER NAVIGATION

Acoustic Doppler, or Doppler sonar, is a relatively new development. It provides a new form of motion sensor, making it possible to measure (a) speed with respect to the bottom; (b) distance traveled; and (c) drift angle, which when added to true heading provides the true course made good over the bottom. In principle, it makes use of the phenomenon of "Doppler Shift" as in satellite navigation; it differs o[
tionally from NAVSAT in that the Doppler measured is in a sea-water medium. Import the Doppler shift phenomenon occurs throu the frequency spectrum, and is equally appli to visible light, electromagnetic waves, acoustic or sound waves. Of prime conside in Acoustic Doppler is the speed of soun signal attenuation and reverberation of radiation in the sea-water medium.

Acoustic Doppler is in one respect si to inertial navigation since both systems r sent improvements to ordinary dead reck Unlike inertial navigation, Acoustic Dopp limited in depth. When the ocean bed is us a reflecting surface, its use is limited by attenuation to depths under the keel of les 100 fathoms. However, echoes from therm dients and marine life can be used in D navigation, provided such reverberations p a signal level greater than the noise level receiver.

A "Doppler Navigator" developed Raytheon Company and designated the AN/S uses four beams of sonic energy, spac apart. Transducers, activated by a trans send out the sound signal and receive th Serving as hydrophones, the transduce vert the echoes into electrical energy. ceiver amplifies and compares the el input from the four transducers and d the Doppler frequency. The receiver a comparison of frequency shifts, senses and direction. The transducer array is geographically by an input from the ship compass. It is also stabilized in the ho plane by the gyrocompass.

Acoustic Doppler Navigation wi AN/SQS-12, as in satellite and inertial s provides a highly accurate direct rea latitude and longitude, and automatic t A smaller Doppler navigator developed f depths less than 250 feet by small c designated the Janus SN-400, displays th in digital form and requires manual

CHAPTER 10

NAUTICAL ASTRONOMY

1001. ASTRONOMY

Celestial navigation is dependent upon certain principles of astronomy, particularly as the latter relates to the positions, magnitudes, and motions of celestial bodies. Astronomy is considered to be the oldest of the sciences. The term "astronomy" is derived from the compounding of two Greek words, "astron" meaning a star or constellation, and "nomos" or law, and is translated literally as the "law of the stars." Ordinarily, it is defined as the science which treats of the heavenly bodies. It is indeed a science of great antiquity.

Three great systems of astronomy have evolved. The Ptolemaic system, now considered an hypothesis, was originated by the Alexandrian astronomer Ptolemy in the second century A.D. Ptolemy placed the earth at rest in the center of the universe, with the moon, Mercury, Venus, the sun, Mars, Jupiter and Saturn revolving about it. The second system, also an hypothesis, was originated by Tycho Brahe in the sixteenth century. Brahe had tried to reconcile astronomy with a literal translation of Scripture, and in so doing, developed a new concept of the solar system. In the Brahean system, the earth is at rest with the sun and the moon revolving about it; the other planets are considered to be revolving about the sun. The third system, which actually antedated that of Tycho Brahe, was conceived earlier in the sixteenth century by the mathematician and astronomer Nicolaus Copernicus. The Copernican theory, now universally adopted as the true solar system, places the sun at the center, with primary planets, including the earth, revolving about the sun from west to east. The earth is considered to be turning on its axis, and the moon is revolving about the earth. Other secondary planets revolve about their primaries. Beyond the solar system, fixed stars serve as centers to other systems. The Copernican concept is the basis of modern astronomy. Further refinements have been made by noted astronomers such as Johann Kepler. Through his work, which followed that of Tycho Brahe, the true nature of planetary orbits was realized. (See Appendix B for Kepler's laws.)

With this brief introduction to astronomy, that portion with nautical significance is further considered. Predicted positions of celestial bodies will be compared with observed positions. Such comparisons provide the basis for celestial lines of position.

1002. UNIVERSE IN MOTION

Motion in the universe is viewed as actual and apparent. We will commence our study by considering the actual motion of (a) the earth, (b) the sun, (c) the planets, (d) the moon, and (e) the stars and galaxies.

a. The earth, the platform from which we observe the universe, engages in four principal motions as follows:

1. Rotation. The earth rotates once each day about its axis, from west to east. The period of rotation is the basis of the calendar day. We can prove the direction of rotation by observing the flow of water from an ordinary wash basin filled with water; when the stopper is removed and the water is allowed to run down the drain, the water will spiral clockwise in the southern hemisphere and counterclockwise in the northern hemisphere. The reason for this action by the water is that two forces are acting upon it. First, gravity acts to cause the water to flow down the drain. Secondly the rotation of the earth, a force that is considered to be concentrated at the earth's equator, acts upon the column of water causing spiral motion, the direction of the spiral depending upon which side of the concentrated force the water column happens to be located.

2. Revolution. The earth revolves about the sun once each year (365 1/4 days), from west to east. The period of revolution is the basis of the calendar year. The difference between rotation and revolution is that rotation is commonly used to refer to turning on an axis while revolution usually refers to travel in an orbit. The actual length of time required for the earth to complete one revolution is a little less than 365 1/4 days and therefore the establishment of an accurate calendar has been a problem. The Gregorian calendar, which replaced that of Julius Caesar, practically eliminated the discrepancy by the elimination of 3 leap years (3 days) per 400 years. This was accomplished by eliminating leap years on turns of the century not divisible by 400. For example, the years 1700, 1800, and 1900 were 365 days in length, while the year 2000 will be 366 days (leap year) in length. Although the calendar of Pope Gregory leaves something to be desired, its error is only 3 days in 10,000 years.

The earth's orbit is elliptical; during the winter months in the northern hemisphere, the earth travels nearer the sun, thus making the sun appear wider in diameter at that time. Also, due to the sun's proximity, the relative speed of the earth as compared to that of the sun is greater in winter than during the summer months in the northern hemisphere, resulting in northern winters being 7 days shorter than northern summers, and southern winters being 7 days longer than southern summers. The average speed of the earth in its orbit is 18 1/2 miles per second.

3. Precession. The earth precesses about an ecliptic axis (i.e., a line passing through the earth's center perpendicular to the plane of the earth's orbit) once each 25,800 years in a counterclockwise direction. This motion is analogous to the motion sometimes observed in a spinning top. When a top is spun, two forces act, (1) the spinning force which tends to keep the top upright and (2) the force of gravity which tends to pull the top from an upright position. The result of these two forces is precession, which is the conical motion of an axis around a perpendicular to the plane upon which it is spun. The earth has a spinning motion of rotation about its axis, which is not perpendicular to the plane of its orbit, and it is acted upon by the gravitational forces of attraction of the moon and the sun; these gravitational torques tend to align the earth's axis with the ecliptic axis. The result of the earth's precession is a difference in location of the stars in our heavens with respect to our north pole. At present, Polaris (north star) is almost directly above the north pole of the earth. In years to come a vertical line through our north pole will point to other stars. It will point in the direction of Deneb in the year 10,000 and in the direction of Vega in 14,000. Again in the year 27,900 Polaris will be above our north pole.

4. Space Motion. The earth and the other members of our solar system are moving through space in the direction of the star Vega at a speed of about 12 miles per second.

b. The sun, the center of our solar system, rotates upon its axis, which is inclined 7 degrees to its path of travel, and travels through space as does the earth.

c. The planets of our solar system rotate upon their axes from west to east, revolve about the sun from west to east in ellipses of small eccentricity, and engage in space motion.

d. The moon, a secondary planet, rotates upon its axes from west to east, revolves about the earth from west to east once in 29 1/2 solar days, and joins other members of our solar system in space motion. The period of rotation of the moon upon its axis, the rotation of the earth, and the revolution of the moon about the earth, is so synchronized that from the earth we see but one side of the moon.

e. The stars engage in space motion and also rotation as does the sun. They are arranged in groups called galaxies. Our galaxy, the Milky Way, contains possibly 100 billion stars. The universe may contain 100 million galaxies, all of which have space motion independent of, and more significant than, the space motion of our solar system. The stars are considered to be an infinite distance from the earth.

A notable observation in the case of actual motion is that most bodies of the universe rotate from west to east, travel from west to east in their orbits, and according to some theories, behave in general as electrons in the structure of the atom.

The astronomer studies actual motion; the navigator concerns himself with apparent motion. The navigator stops the earth, so to speak, and observes the celestial bodies rise in the east, travel westward, and set in the west. The astronomer tabulates information which the navigator uses to fix his position.

1003. CELESTIAL SPHERE CONCEPT

Because of the necessity for location of celestial bodies in the heavens, we use a system of coordinates similar to latitude and longitude on the surface of the earth; the system established is known as the celestial sphere concept. The following terms constitute the concept:

CELESTIAL SPHERE. — A sphere of infinite radius with the earth as center. Whenever convenient we think of the earth as a point, and as a point it has no magnitude. We portray all of the heavenly bodies on the surface of the celestial sphere. We consider apparent rather than actual motion, and thus actual distances are immaterial.

CELESTIAL POLES. — Points on the surface of the celestial sphere which mark the point of intersection of the celestial sphere and the earth's axis extended. The north celestial pole is abbreviated Pn and the south celestial pole is abbreviated Ps.

ELEVATED POLE. — The celestial pole which corresponds in name to the observer's latitude.

EQUINOCTIAL. — A great circle on the surface of the celestial sphere everywhere 90 degrees from the celestial poles. Sometimes called the CELESTIAL EQUATOR, the equinoctial lies in a plane which is the plane of the equator extended to intersect the celestial sphere and which is perpendicular to the axis of the earth (and of the celestial sphere). The equinoctial, like the equator, supplies a reference for north-south measurement.

CELESTIAL MERIDIAN. — A great circle on the surface of the celestial sphere which passes through the celestial poles and over a given position on earth. There are an infinite number of celestial meridians. Each meridian has an upper branch (180 degrees of arc passing over a position and terminating at the celestial poles) and a lower branch (remaining 180 degrees of arc). In common usage, the term "celestial meridian" refers to the upper branch.

HOUR CIRCLE. — A half of a great circle on the surface of the celestial sphere which passes through a celestial body and terminates at the celestial poles. The hour circle, contrasted to the celestial meridian, moves with the celestial body progressively with time from east to west (since we consider apparent motion), while the position of the celestial meridian remains fixed. With knowledge of the earth's rotation (one turn upon its axis per 24 hours) we can realize that each celestial body crosses our meridian once each 24 hours. Dividing 360 degrees (number of degrees in a circle) by 24 hours, we find that an hour circle advances about 15 degrees per hour.

DECLINATION. — The angular distance of a body north or south of the equinoctial measured along the hour circle. Declination resembles latitude and like latitude must be labeled north or south. Declination is abbreviated "dec."

GREENWICH HOUR ANGLE (GHA). — The angle between the celestial meridian of Greenwich, England, and the hour circle of a body, measured westward along the arc of the equinoctial, and expressed in degrees from 0 to 360. Also equal to the angle at the celestial pole between the Greenwich celestial meridian and the hour circle, measured westward.

LOCAL HOUR ANGLE (LHA). — The angle between the celestial meridian of the observer and the hour circle of a body, measured westward along the arc of the equinoctial, and expressed in degrees from 0 to 360. Also equal to the angle at the celestial pole between the local celestial meridian and the hour circle, measured westward. In west longitude LHA is found by subtracting the longitude of the observer from the GHA. In east longitude LHA is found by adding the longitude of the observer to the GHA.

ECLIPTIC. — The apparent path of the sun among the stars over a period of a year; a great circle on the surface of the celestial sphere lying in a plane which intersects the plane of the equinoctial making an angle of approximately 23 1/2 degrees.

ZODIAC. — A belt extending 8 degrees to each side of the ecliptic. The apparent paths of all the planets within our solar system fall within this belt except for Venus which occasionally appears to travel outside the zodiac. The zodiac was divided into 12 sectors (signs) by the ancients to correspond to months, each sector being named for the constellation which the sun appeared to be passing through or near at that time. Each sector or sign extends 30 degrees in arc.

EQUINOXES. — Two great circles on a spherical surface share two points of intersection. The points of intersection of the equinoctial and the ecliptic are called the vernal equinox (March equinox) and the autumnal equinox. The sun normally arrives at the vernal equinox on March 21; at that time (the beginning of spring), the declination of the sun is 0 and the sun passes from south to north declination. The sun normally arrives at the autumnal equinox on September 23; at that time (the beginning of autumn), the declination is also 0 and the sun passes from north to south declination.

SOLSTICES. — When the sun reaches its maximum northern declination (23 1/2 N) on or about June 22, we speak of the time as the summer solstice (the beginning of summer). When the sun reaches its maximum southern declination (23 1/2 S) on or about December 22, we speak of the time as the winter solstice (the beginning of winter).

DIURNAL CIRCLE. — A small circle on the surface of the celestial sphere which describes the apparent daily path of a celestial body. The diurnal circle of the sun at the summer solstice projected to the earth is called the Tropic of Cancer; located 23 1/2 degrees north of the equator, and named for the sign of the zodiac containing the sun at that time, it marks the northern limit of the tropics. The diurnal circle of the sun at the winter solstice projected to the earth is called the Tropic of Capricorn; located 23 1/2 degrees south of the equator, and named for the sign of the zodiac containing the sun at that time, it marks the southern limit of the tropics. When the sun is over the Tropic of Cancer (summer solstice), its rays extend 90 degrees to either side causing continual daylight (midnight sun) in the region north of 66 1/2 degrees North Latitude, and continual darkness in the region south of 66 1/2 degrees South Latitude. When the sun is over the Tropic of Capricorn, the region north of 66 1/2 degrees North Latitude has continual darkness and the region south of 66 1/2 degrees South Latitude has continual daylight. This is the basis for our establishment of the Arctic and Antarctic Circles.

FIRST POINT OF ARIES. — Abbreviated by (the ram's horns or the Greek letter upsilon), the first point of Aries is a reference point on the ecliptic and is another name for the vernal or March equinox. Although it is an imaginary point, we may establish an hour circle through it for measurement of sidereal hour angle and right ascension.

SIDEREAL HOUR ANGLE (SHA). — The angle between the hour circle of the first point of Aries and the hour circle of a body measured westward along the arc of the equinoctial, expressed in degrees from 0 to 360. The word "sidereal" normally means "of or pertaining to stars" and the SHA for navigational stars is tabulated in the Nautical Almanac. SHA, unlike the other hour angles, does not increase with time but remains relatively constant. The reason for this is that the hour circles between which the measurement is made are traveling at practically the same speed, and thus have a relative speed of nearly zero.

RIGHT ASCENSION. — The angle between the hour circle of the first point of Aries and the hour circle of a body, measured eastward along the arc of the equinoctial, and expressed in either degrees or in hours. Right ascension (in degrees) plus sidereal hour angle equals 360 degrees.

TRANSIT. — The passage of a body across a meridian. The crossing of the upper branch of the celestial meridian is the "upper transit"; the crossing of the lower branch is the "lower transit."

CULMINATION. — A synonym of "upper transit."

MERIDIAN ANGLE (t). — The angle between the celestial meridian of the observer and the hour circle of a body measured eastward or westward along the arc of the equinoctial from the celestial meridian, and expressed in degrees from 0 to 180. Meridian angle always carries a suffix "E" or "W" to indicate direction of measurement. When LHA is less than 180 degrees, t equals LHA, and is labeled west. When LHA is greater than 180 degrees, t equals 360-LHA, and is labeled east.

POLAR DISTANCE. — The angular distance of a body from the elevated pole measured along the hour circle. When declination and elevated pole are of the same name (both north or both south), polar distance is the complement of declination and may be referred to as co-dec. When elevated pole and declination are of different names (one north and one south), polar distance equals 90 degrees plus declination.

1004. TIME DIAGRAM

The relationship between various reference circles of the celestial sphere which measure angular quantities in an east-west direction may be best understood through the construction of a time diagram. This is a view of the celestial sphere, in the plane of the equinoctial, as seen from the south celestial pole. Easterly direction is clockwise and westerly direction is counterclockwise. A radial line is drawn from Ps in the center, in any direction, but generally in the vertical, to locate the celestial meridian of the observer. From the celestial meridian, using the observer's longitude, the celestial meridian of Greenwich is located and plotted. From the celestial meridian of Greenwich, using tabulated GHA's, the hour circles of the sun, the planets, the moon, and the first point of Aries may be plotted. From the hour circle of the first point of Aries, using SHA as tabulated, the hour circle of the stars may be located and plotted. This diagram makes possible the derivation of (1) LHA, and (2) t.

Typical time diagrams are illustrated in figure 10-1. Figure 10-2 illustrates certain additional relationships.

From the time diagram we may derive the following relationships:

LHA = GHA - W λ
LHA = GHA + E λ
GHA* = GHA♈+SHA*
LHA* = LHA♈+ SHA*
RA = 360 - SHA
SHA = 360 - RA
t = LHA, if LHA is less than 180 degrees
t = 360 - LHA, if LHA is greater than 180 degrees.
If t = LHA, t is west.
If t = 360 - LHA, t is east.

1005. HORIZON SYSTEM OF COORDINATES

Location of points on the celestial sphere by declination and hour angle is not always practical for an observer, since the equinoctial is an imaginary circle. For the observer, the horizon offers a better reference. The horizon system employs the following terms.

ZENITH. — Point on the celestial sphere directly above the observer. Abbreviated "Z". A point on the surface of the earth having a star in its zenith is called the star's geographic position, sub-astral, or ground point.

NADIR. — Point on the celestial sphere directly below the observer. Abbreviated "Na."

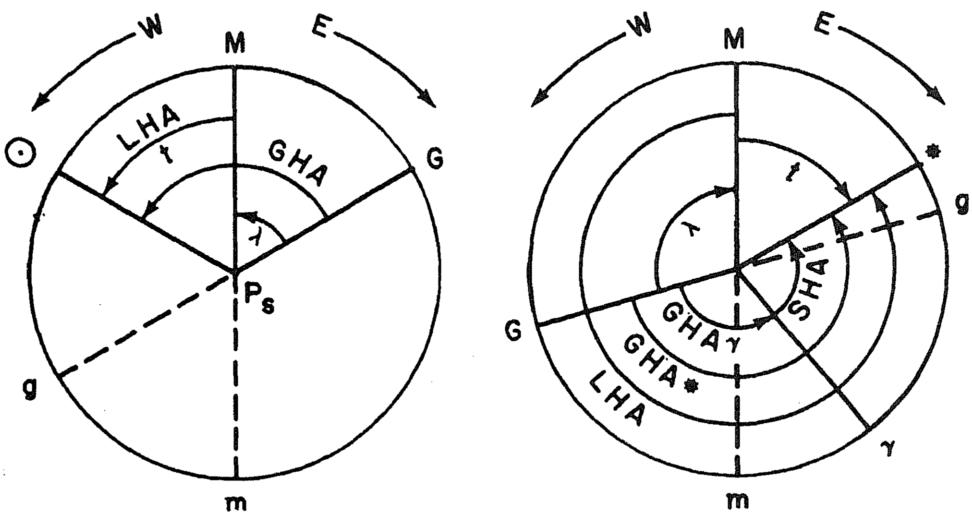
CELESTIAL HORIZON. — A great circle on the surface of the celestial sphere everywhere 90 degrees from the zenith. The visual horizon is the line at which the earth appears to meet the sky. If a plane is passed through the observer's position and perpendicular to the zenith-nadir axis we have the sensible horizon. The visual horizon is corrected to the sensible horizon by application of a correction for height of observer's eye. If a plane is passed through the center of the earth perpendicular to the zenith-nadir axis, we have the rational horizon. When projected to the celestial sphere, both the sensible and the rational horizon meet at the celestial horizon. This occurs because the planes of the sensible and rational horizons are parallel and parallel lines meet at infinity (the radius of the celestial sphere).

VERTICAL CIRCLE. — A great circle on the surface of the celestial sphere passing through the zenith and nadir and through some celestial body. Although it is by definition a complete circle, in actual usage we speak of the 180 degrees through the body and terminating at the zenith and nadir respectively, as the vertical circle. In practice we make use of the 90 degree arc from the zenith to the horizon through the body; the remaining 90 degrees below the horizon is not visible and serves no purpose.

PRIME VERTICAL. — A vertical circle passing through the east and west points of the horizon. The prime vertical arc above the horizon terminates at the points of intersection of the equinoctial and the celestial horizon.

ALTITUDE (h). — The angular distance of a body above the horizon measured along the vertical circle.

ZENITH DISTANCE. — The angular distance of a body from the zenith measured along the vertical circle; it is the complement of the altitude and is abbreviated either "z" or "co-alt."



A. WEST LONGITUDE B. EAST LONGITUDE

LEGEND:

M – Upper branch of observer's meridian
m – Lower branch of observer's meridian
G – Upper branch of Greenwich meridian
g – Lower branch of Greenwich meridian
⊙ – Hour circle of sun
♈ – Hour circle of First Point of Aries
✱ – Hour circle of star
Ps – South Celestial pole
λ – Longitude
GHA – Greenwich hour angle
LHA – Local hour angle
t – Meridan angle
SHA – Sidereal hour angle

190.15

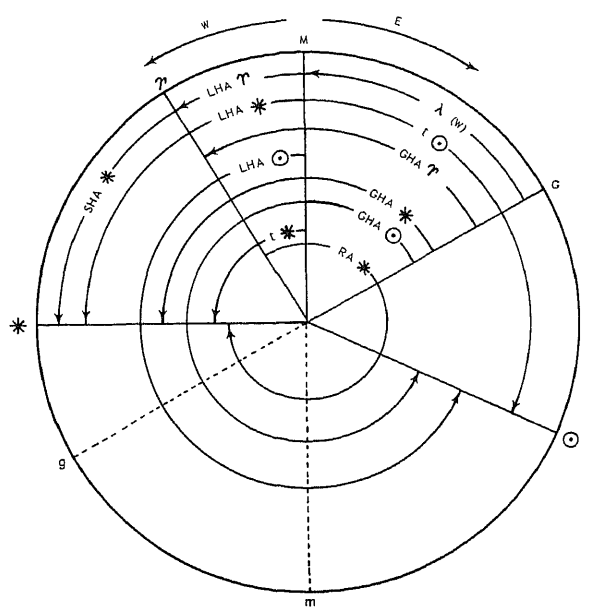
Figure 10-1.—Time diagrams. (a. West Longitude, b. East Longitude.)

AZIMUTH (Zn).—The true direction of a celestial body; the angle between the celestial meridian and the vertical circle measured right or clockwise from north to the vertical circle.

AZIMUTH ANGLE (Z).—The angle between the local celestial meridian and the vertical circle; the arc of the horizon measured from either the north or south points of the horizon (depending upon which pole is elevated) right or left to the vertical circle and expressed in degrees from 0 to 180. Azimuth angle must be prefixed by N or S to indicate which is the elevated pole, and suffixed by E or W to indicate the direction of measurement. If meridian angle is east, the suffix will be "E"; if meridian angle is west, the suffix will be "W."

We may establish certain relationships between azimuth and azimuth angle (see fig. 10-3) as follows:

(a) When azimuth angle is measured north to east (north pole elevated, east meridian angle), azimuth equals azimuth angle.



From the time diagram we may derive the following relationships:

$LHA = GHA - W\ \lambda$
$LHA = GHA + E\ \lambda$
$GHA* = GHA\Upsilon + SHA*$
$LHA* = LHA\Upsilon + SHA*$
$RA = 360 - SHA$
$SHA = 360 - RA$
t = LHA, if LHA is less than 180 degrees
t = 360 - LHA, if LHA is greater than 180 degrees
If t = LHA, t is west
If t = 360 - LHA, t is east.

190.16
Figure 10-2.—Time diagram.

(b) When azimuth angle is measured north to west (north pole elevated, west meridian angle), azimuth equals the explement of, or 360 minus, the azimuth angle.

(c) When azimuth angle is measured south to east (south pole elevated, east meridian angle), azimuth equals the supplement of azimuth angle.

(d) When azimuth angle is measured south to west (south pole elevated, west meridian angle), azimuth equals 180 degrees plus azimuth angle.

LATITUDE OF THE OBSERVER.—This value is projected on the celestial sphere as the angular distance between the equinoctial and the zenith, measured along the celestial meridian.

POLAR DISTANCE OF THE ZENITH.—The angular distance between the zenith and the elevated pole measured along the celestial meridian; the complement of the latitude and usually referred to as "co-lat."

1006. ASTRONOMICAL TRIANGLE

Combining the celestial sphere concept and the horizon system of coordinates (fig. 10-4A), we derive a triangle on the surface of the celestial sphere known as the astronomical triangle (fig. 10-4B). This triangle projected back to the earth's surface is the navigational triangle; in practice, the terms astronomical and navigational as applied to triangles are synonomous.

In the astronomical (or navigational) triangle as illustrated, two sides and the included angle are given (co-lat, t, co-dec) and the opposite side (co-alt) and one angle (Z) are solved for. Actually, latitude of the observer and co-lat are not known exactly, but are assumed, as is longitude in arriving at "t." The actual altitude is measured, and, by its comparison with the computed altitude, the discrepancy in the assumptions of latitude and longitude may be determined.

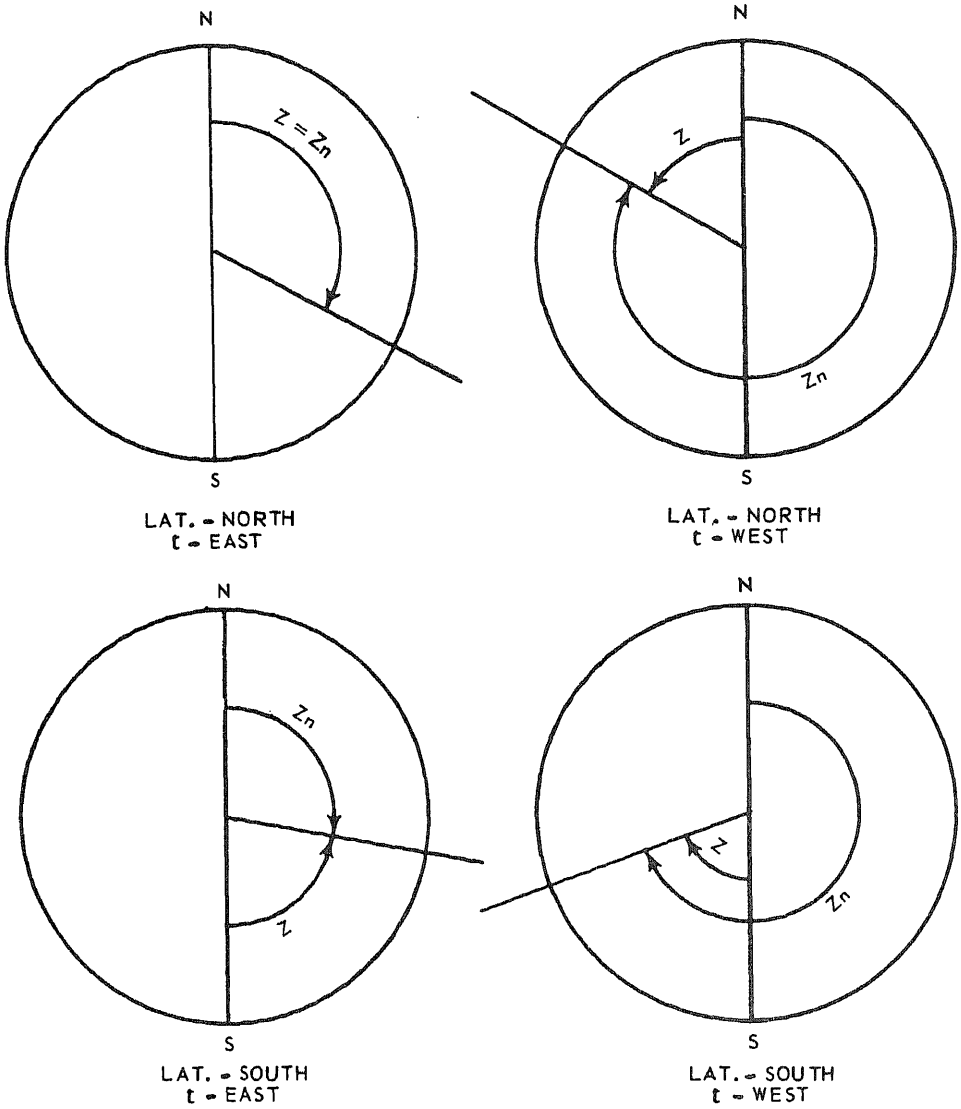
Solution of the astronomical triangle may be accomplished using the cosine-haversine law. However, practical navigators no longer resort to spherical trigonometry for the solution of the triangle. Instead they make use of such tables as H.O. 214 which actually are tabulations of the results of solutions of all possible triangles. In preparing these tables, it was customary to break the astronomical triangle into two right spherical triangles by dropping a perpendicular from one vertex to the opposite side. For convenience, these tables are so tabulated as to make unnecessary the computation of complements.

1007. SPECIAL CELESTIAL RELATIONSHIPS

The relationships below are worthy of note in any study of the celestial sphere:

(a) A body on the observer's celestial meridian has an azimuth of either 000 or 180 and is either at its greatest or least altitude depending upon whether it is transiting the upper or lower branch of the meridian.

(b) A body on the prime vertical has an azimuth of either 090 or 270.



190.17
Figure 10-3. — Azimuth angles and azimuth.

(c) When a body is on the horizon it is either rising or setting.

(d) When the declination and latitude are of the same name, the body will be above the horizon more than half the time, and it will rise and set between the prime vertical and the elevated pole.

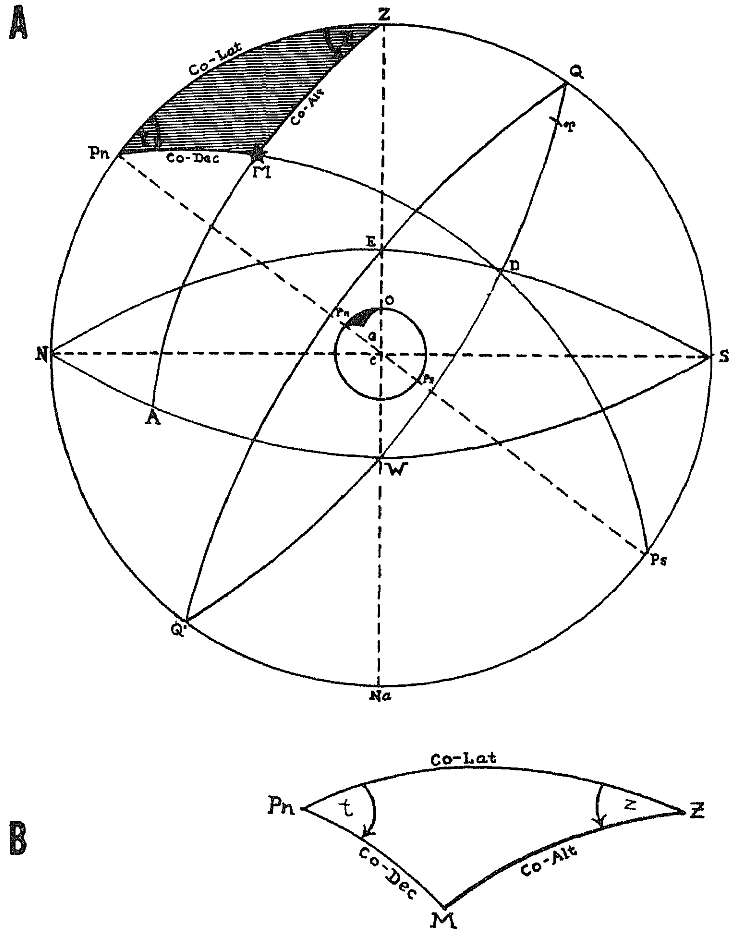
(e) If declination and latitude are of the same name and equal, the body will pass through the zenith. When in the zenith, it has no azimuth or azimuth angle.

(f) When the declination is of the same name as the latitude and numerically greater than the co-lat, the body is circumpolar (it never sets).

(g) When declination is 0 degrees, a body rises in the east and sets in the west.

(h) When the declination is of contrary name (as compared to latitude), and greater than the co-lat, the body never rises.

(i) At the equator, the celestial poles coincide with the celestial horizon. There are no



The parts of the adjacent figure are:

c	Common center of terrestrial & celestial spheres.
N,E,S,W,	Observer's north, east, south & west points respectively on the horizon.
NESWAN	Observer's horizon.
Pn & Ps	North & South celestial poles (also poles of the earth).
Z & Na	Zenith & Nadir.
Q & Q'	Points of intersection of equinoctial with upper and lower branches of the observer's meridian.
NPnZQSPsNaQ'	Celestial meridian of the observer.
EQ♈DWQ	Equinoctial.
♈	Vernal equinox or first point of Aries.
ZQ	Latitude of the observer.
O	Terrestrial point of the observer.
PnMDPs	Hour circle of celestial body M.
M	Celestial body.
ZMA	Vertical circle of body M.
G	Ground point.
DM	Declination of star M.
♈D	SHA of star M.
♈QEQ'WD	RA of star M.
QD	LHA of star M.
NA	Azimuth angle of star M.
NESWA	Azimuth of star M.
AM	Altitude of star M.
t	Meridian angle.
Z	Azimuth angle measured at zenith.
PnM	Co-dec or polar distance.
MZ	Co-alt or zenith distance.
PnZ	Co-lat or polar distance of the zenith.
PnZM	Astronomical triangle.
PnOG	Navigational triangle.

69.56

Figure 10-4. — The celestial sphere. B. Astronomical triangle.

circumpolar stars nor stars that never rise. Stars rise and set in planes which are perpendicular to the plane of the horizon.

(j) At the poles, the equinoctial coincides with the celestial horizon, the only bodies visible are those with a declination of the same name as latitude, and all these are circumpolar. Altitude then equals declination, and azimuth is insignificant since all directions at the north pole are south and at the south pole all directions are north.

CHAPTER 11

TIME

1101. INTRODUCTION

With the nautical astronomy background gained through the study of Chapter 10 as a prerequisite, the practice of celestial navigation may now be approached, commencing with a brief study of time and timepieces.

During the Newtonian era, great advances in mathematics and in the physical sciences made available (a) a great deal of information concerning the positions of stars and planets; (b) greater knowledge of gravitation; and (c) more information in general concerning the celestial bodies beyond our solar system. The Post-Newtonian era was characterized by the practical application of the new knowledge of astronomy.

An early problem was that of determining longitude at sea. As we shall see in Chapter 13, latitude can be readily determined by a meridian sight without knowledge of exact time or resort to spherical trigonometry. However, longitude can not be so easily obtained. Accordingly, in 1714, British sea captains petitioned the House of Commons for a solution to the problem of determining longitude. By 1735, John Harrison had produced a marine chronometer which advanced considerably the practice of navigation, making it possible to more accurately compute longitude.

1102. TIME MEASUREMENT

With this brief historical introduction, time may now be defined as the sum of all the days in the past, today, and all the days of the future. However, we think of time, as a quantity which can be measured. Time may be expressed as a measured duration, such as three hours, and also as "clock time," for example, 0200. The instrument for making this measurement is a timepiece. The earth is our celestial timepiece. Each turn upon its axis provides a unit of time known as the day. Time is important to the navigator because as we have seen, of its relationship to longitude.

Two general types of time measurement are solar time and sidereal time. Solar time is based upon the rotation of the earth with respect to the sun while sidereal time is based upon the rotation of the earth with respect to the stars.

1103. SOLAR TIME

We will at first restrict our discussion to solar time, commencing with a type called apparent time which is time measured upon the basis of the apparent motion of the real sun. By apparent time, when the sun transits the upper branch of the local celestial meridian, the time is spoken of as local apparent noon (LAN) or 1200 apparent time. When the sun transits the lower branch of the local celestial meridian, the time may be spoken of as local apparent midnight or 2400 (also 0000). Unfortunately, the length of the apparent day varies. This results because of two reasons:

(a) The ellipticity of the earth's orbit. The earth when relatively near the sun rotates once with respect to the sun in less time than when relatively far from the sun. This occurs because the earth is moving in its orbit while rotating.

(b) The sun's apparent movement with respect to the earth is faster at the solstices, when the sun is moving almost parallel to the equinoctial, than at the equinoxes when the direction of the sun's apparent motion has a larger north-south component.

Since apparent days are unequal in length it is impractical for man-made timepieces to keep apparent time, and as an expedient we have averaged the length of the 365 1/4 apparent days (1 solar year) and arrived at a measurement known as mean time. One mean day is 24 hours in length, each hour consisting of 60 minutes and each minute consisting of 60 seconds. We can say that mean time is based upon the motion of

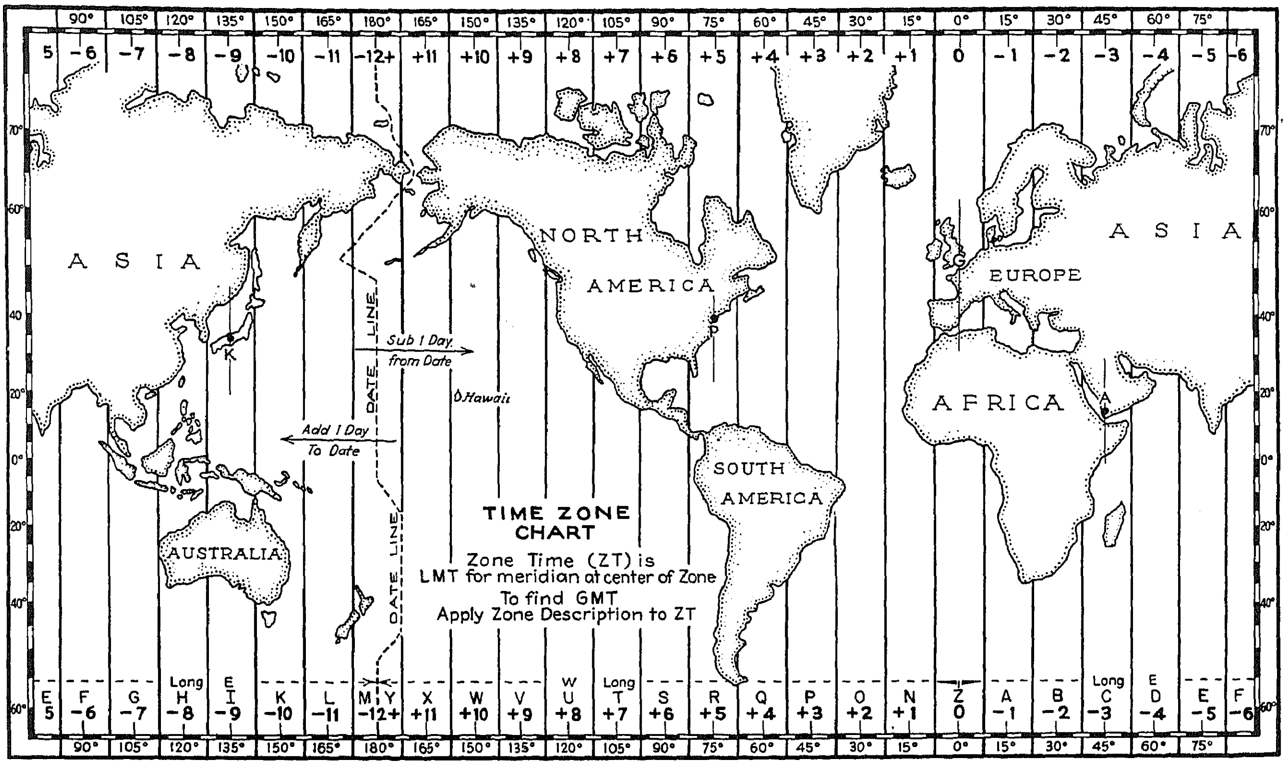
an imaginary sun moving westward in the equinoctial at a uniform speed. At the instant the imaginary sun transits the upper branch of the local celestial meridian, we witness local mean noon (1200 local mean time), and at the instant the imaginary sun transits the lower branch of the local celestial meridian, we observe local mean midnight (2400 or 0000 local mean time). The difference between mean time and apparent time is the "equation of time," a value which is tabulated in the Nautical Almanac.

Mean time changes with longitude, and since there are an infinite number of local celestial meridians the keeping of mean time is a system lacking in uniformity. To keep a timepiece set to mean time, we would have to reset it with each change in position. Since this would be just as impractical as using apparent time, we have established standard or zone time, (fig. 11-1) abbreviated ZT, which provides that a zone 15 degrees wide in longitude may keep the same time throughout the zone. THE ZONE TIME OF ANY ZONE IS THE MEAN TIME OF THE CENTRAL MERIDIAN. The geographic extent of the time zone is 7 1/2 degrees to either side of the central meridian. The local mean time for a meridian may be converted to zone time. This is accomplished by (1) converting the difference in longitude (between local and standard meridians) from arc to time, and (2) adding such correction to the local mean time if the local meridian is to the west and subtracting it if to the east. See articles 1303 and 1305 for examples of conversion of local mean time to zone time. Conversely, zone time may be converted to local mean time. The origin of time zones is the meridian of Greenwich which is the central meridian of time zone "0." Time zone 0 keeps standard or zone time which is exactly the same as the mean time of Greenwich, abbreviated GMT. In all time zones, except 0 zone, the longitude of the central meridian is divisible by 15. Each time zone is assigned a zone description (ZD). The zone description consists of a number from 0 to 12 commencing with 0 at Greenwich and counting both to the east and to the west. Time zones in the eastern hemisphere are distinquished from the time zones in the western hemisphere by a prefix; eastern time zones are prefixed by a minus sign while western time zones are prefixed by a plus sign. The zone description indicates the hours difference between the zone time of a zone and GMT; applying the ZD in accordance with sign to the ZT we arrive at GMT. For example, longitude 175 West is in a time zone known by the zone description + 12 (175/15). If the zone time is 11-09-22 (conventional means of expressing hours, minutes, and seconds), then GMT is 11-09-22 plus 12-00-00 or 23-09-22. If our longitude is 36 East, our ZD must be -2, and if ZT is 08-16-32, GMT must be 08-16-32 minus 02-00-00 or 06-16-32. Since we can find GMT by applying the ZD according to sign to the ZT, conversely, we can find ZT by applying the ZD with the sign reversed to GMT.

The 180th meridian is the central meridian of time zone 12 which is common to both hemispheres. However the half in the eastern hemisphere has a ZD of -12, and the half in the western hemisphere has a ZD of +12. For this reason, and since the Greenwich time zone is known as 0, we have 24 time zones but 25 zone descriptions.

Sometimes, in order to make the best use of daylight hours, all clocks are advanced 1 hour; this system of keeping time is call daylight saving time. In time of war, clocks may be advanced 1 hour and the time referred to as war time. When either daylight saving or war time is being kept, in effect, the zone is keeping the standard time of the adjacent zone to eastward, and instead of observing the sun on the meridian between 1130 and 1230, upper transit of the central meridian will occur normally between 1230 and 1330.

The time zone system has been generally adopted except in Saudi Arabia, in the polar regions, and in a few remote islands. Saudi Arabia keeps "Arabic time" by which all timepieces are set to midnight at sundown. Through island groups and over land, the time zone boundaries may be somewhat irregular. For example, the eastern time zone in the U.S. (ZD + 5) is separated from the central time zone (ZD + 6) in the north by the west shore of Lake Michigan and in the extreme south by the Appalachicola River of Florida. Ordinarily at sea, as a ship proceeds from one time zone to another, ship's clocks are reset. When traveling in company with other vessels, the officer in tactical command may be expected to initiate the signal. When steaming independently, the zone time is changed at the discretion of the commanding officer. When traveling eastward, zone time



13.76(69)
Figure 11-1.—Standard time zones.

is changed by advancing the clocks 1 hour. When traveling westward, the clocks are retarded 1 hour upon entering a new time zone.

When the sun transits the celestial meridian of Greenwich, the date throughout the world is the same. At every other instant, there are two dates in the world simultaneously. The new local date at a given location on the earth begins with the sun's transit of the lower branch of the celestial meridian; the new Greenwich date begins with the sun's transit of the 180th meridian (which with occasional deviations for the benefit of island groups is the international date line). Within the 12th time zone all time is the same but the date in the western hemisphere section is always 1 day earlier than in the eastern hemisphere section. When traveling from the western hemisphere to the eastern we advance the calendar 1 day (for example, 2 Jan. to 3 Jan.); when traveling from the eastern hemisphere to the western hemisphere we retard the calendar 1 day (for example, 2 Jan. to 1 Jan.).

In a time diagram if the hour circle of a celestial body plots between the lower branches of the local celestial meridian and the Greenwich celestial meridian, the local date differs from the Greenwich date. If the local meridian is in west longitude the Greenwich date is 1 day later than the local date; if the local meridian is in east longitude, the local date is one day later than the Greenwich date. When ZD is applied to ZT to obtain GMT, if the GMT is over 24 hours, then 24 hours must be subtracted; the remainder is the GMT and the Greenwich date is 1 day later than the local date. If, when ZD is applied to ZT to obtain GMT, the result is anticipated to be a minus value because of the necessity of subtracting ZD, the navigator adds 24 hours to the ZT before subtracting the ZD and notes that the Greenwich date is a day earlier than the local date. It is necessary to know the Greenwich mean time and Greenwich date because upon

it all tabulated astronomical data used by the navigator is based.

EXAMPLE 1: Convert ZT 0800 15 Dec. in ZD+4 to GMT.

SOLUTION:

ZT	0800 15 Dec.
ZD	+4
GMT	1200 15 Dec.

EXAMPLE 2: Convert ZT 1500 28 Dec. in longitude 81°E to GMT.

SOLUTION: ZD = 81/15 = -5

ZT	1500 28 Dec.
ZD	-5
GMT	1000 28 Dec.

EXAMPLE 3: Convert ZT 0500 12 Jan. in longitude 167° -30'E to GMT.

SOLUTION: ZD = 167 - 30/15 = -11

ZT	0500 12 Jan. or	2900 11 Jan.
ZD		-11
GMT		1800 11 Jan.

EXAMPLE 4: Convert 0600 14 Feb. GMT to ZT in longitude 120°W.

SOLUTION:

ZD = 120/15 = +8

GMT 0600 14 Feb.	or	3000 13 Feb.
ZD +8 (with sign reversed)		-8
ZT		2200 13 Feb.

1104. TIME AND ARC

Since the equinoctial is a circle containing 360 degrees, and since there are 24 hours in a day, we may use these figures to establish a basis for the conversion of arc to time and time to arc. The conversion is as follows:

Time		Arc
24 hrs.	=	360°
1 hr.	=	15°
60 min.	=	15°
4 min.	=	1°
4 min.	=	60'
1 min.	=	15'
60 sec.	=	15'
4 sec.	=	1'
4 sec.	=	60''
1 sec.	=	15''

EXAMPLE 1: Convert 344° 16'33'' to time.

344°	= 22 hrs.	56 min.		
16'	=		1 min.	4 sec.
33''	=			2.2 sec.
Answer:	22 hrs.	57 min.		6.2 sec.

EXAMPLE 2: Convert 18 hrs. 37 min. 20 sec. to arc.

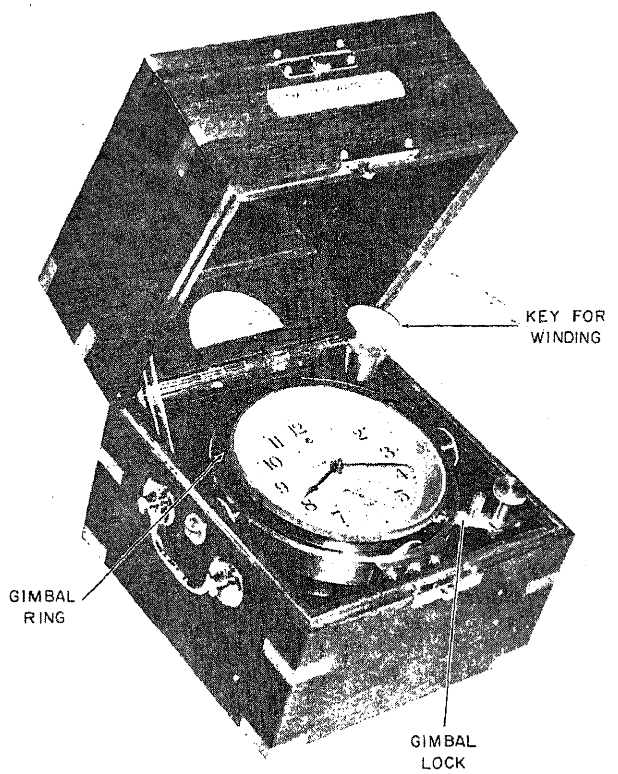
18 hrs.	=	270°	
37 min.	=	9°	15'
20 sec.	=		5'
Answer:		279°	20'

An easier method of conversion is offered by a conversion table in the back of the Nautical Almanac. (See Appendix F-3)

1105. SIDEREAL TIME

Sidereal time, or star time, is based upon the earth's rotation with respect to the stars. Sidereal and solar time differ in the four following ways:

(a) Reference. The sun is the reference point for solar time; the first point of Aries is the reference point for sidereal time.



69.38
Figure 11-2.—Ships chronometer in its case.

(b) Commencement of Day. A solar day commences when the sun transits the lower branch of the local celestial meridian (midnight); a sidereal day commences when the first point of Aries transits the upper branch of the local celestial meridian (sidereal noon).

(c) Date. There is no sidereal date.

(d) Length of Day. A sidereal day is 3 minutes and 56 seconds shorter than a solar day which provides for 366 1/4 sidereal days in a solar year (365 1/4 solar days). The reason for a sidereal day being shorter is the fact that while the earth rotates with respect to the sun it also travels in its orbit. When the earth has rotated once with respect to the stars, its travel in its orbit has necessitated that it turn almost an additional degree in order to have rotated once with respect to the sun.

1106. TIMEPIECES

Timepieces, as previously introduced in art. 309, consist of chronometers, comparing watches, ship's clocks, and stop watches.

The chronometer (fig. 11-2) is the navigator's most accurate timepiece. There are two sizes. The larger, referred to as size 85, is a regular ship's chronometer, made by the Hamilton Watch Company. The smaller, size 35, is a high-grade watch, and is often referred to as a chronometer watch. It is usually stowed so as to be protected against shock, electrical influence, and extreme changes in temperature. Most vessels carry 3 chronometers for comparison purposes thus making it possible for the quartermaster to readily detect the error in any instrument which may develop an erratic rate. The chronometer is set to GMT and never reset until returned to a chronometer pool (source of chronometers used in Navy ships) for cleaning and adjustment which is necessary every 2 to 3 years. The chronometer is wound daily at 1130; this (and the fact that a comparison was made) is reported at 1155 to the commanding officer as part of the 12 o'clock report. Chapter 9240, Section I, Part 3, of the Naval Ships Technical Manual and the chronometer record book contain detailed instruction for chronometer care.

Time signals, for checking the current accuracy of chronometers, may be received from Radio Stations WWV and WWVH, of the National Bureau of Standards, Department of Commerce, transmitting from Colorado and Hawaii respectively, and from Naval Radio Station, NSS, Annapolis, Maryland. Upon receiving a radio time signal, the quartermaster checks the chronometer and establishes the chronometer error, labeling it fast or slow as appropriate. The average daily difference in error, called the daily rate and labeled "gaining" or "losing," is also computed and recorded. With the chronometer error for a given date in the past, and the daily rate, we can predict the chronometer error for either the present or a future date.

Quartz oscillator clocks are coming into use as marine chronometers. Currently, military specifications for such timepieces are being prepared. These clocks, which are electrically

(usually battery) powered, are known to be exceptionally accurate. They are also quite resistant to shock and vibration and do not require gimbal mounting.

The comparing watch is a high grade pocket watch carried by the navigator or quartermaster when making celestial observations. It may be set exactly on GMT since by extending the stem the second hand may be stopped; to set the watch on GMT the quartermaster must mentally consider current chronometer error. Some navigators prefer setting the comparing watch to zone time which necessitates the application of ZD in order to find GMT. If the quartermaster is unsuccessful in setting the watch exactly to zone time or GMT, he should ascertain the watch error (WE on ZT or WE on GMT). Such correction must be applied to the watch time of each observation.

A stop watch may be started upon making a celestial observation; then upon subsequent observations the seconds elapsed may be recorded. At a given instant, upon completion of celestial observations, a comparison may be made with the chronometer and the chronometer time of observation (or observations) computed. By applying the current chronometer error to the chronometer time we arrive at correct GMT. The only advantage of a stop watch is that the second hand reading is easier to make. Whenever reading time for an observation, the hands should be read in the order of their speed — second hand, minute hand, hour hand.

Marine clocks, designated according to usage as boat, deck, or general purpose clocks, are normally of the eight day mechanical type. Some general purpose clocks have 24 hour dials; all others have 12 hour dials. Marine clocks are manufactured by the Chelsea Clock Company, and by Seth Thomas Clocks, Division of General Time Corporation. Clocks are normally wound weekly, and reset as necessary when wound. After winding and setting, the bezel or case must be closed to prevent dust from entering the case.

CHAPTER 12

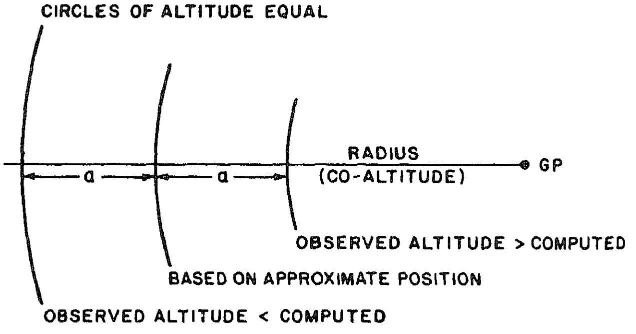
SIGHT REDUCTION

1201. INTRODUCTION

In the advancement of the practice of celestial navigation, perhaps the milestone next following the appearance of Harrison's chronometer was the discovery in 1837 by an American shipmaster, Captain Thomas A. Sumner, of a solution for a celestial line of position. From the observation of an altitude of the sun, he made three computations for longitude using a different latitude in each, because of uncertainty as to his latitude. After a plot of three positions from these computations, he noted that the three could be connected by a straight line, which he correctly assumed to be a locus or line of position. Subsequently, a landfall gave further evidence of the correctness of his assumption. Since Sumner's discovery, solution for and use of such a line of position, has been the essence of celestial navigation.

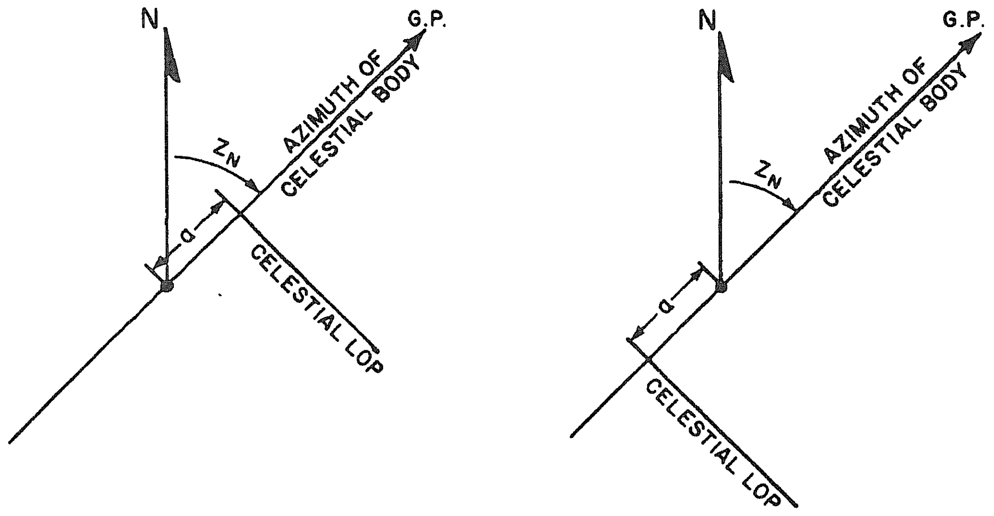
Unfortunately, to obtain a "Sumner's line," multiple computations are required. However, in 1875, the computation was simplified by a procedure introduced by Commander Marcq de St. Hilaire, French Navy. By the St. Hilaire or "Altitude Intercept" method, the altitude and azimuth of a celestial body are computed for an approximate or assumed position of the ship at a given time of observation. By comparison of the observed altitude and the computed altitude, the difference, known as "intercept," is determined in minutes of arc. A line is drawn through the assumed position from which the computed altitude was obtained, in the direction of the azimuth. If the observed altitude is greater than the computed, the observer is nearer the body, and conversely, if the computed altitude is greater than the observed, the observer is farther away; accordingly, the intercept in minutes of arc is directly converted to nautical miles and is measured from the assumed position along the azimuth line, toward or away from the celestial body, as appropriate. At the point thus established, a line of position is drawn, at right angles to the azimuth line. This celestial line of position, although a straight line, is representative of a short arc, taken from a circle of equal altitude drawn about the geographical position (GP) of the observed body. See figures 12-1 and 12-2. Mathematically, a Sumner's line is actually a chord of such a circle; the Marcq de St. Hilaire line is a tangent.

The altitude intercept method as introduced by Commander St. Hilaire was widely adopted. For solution of the astronomical or navigational triangle for computed altitude and azimuth, the use of a cosine-haversine formula was adopted, a haversine of an angle being equal to one half the quantity of one minus the cosine of such angle. Thus, the solution of the triangle, while somewhat easier, still required resort to spherical trigonometry. However, the solution was further simplified by Ogura of Japan, among others, and in the 1930's several new methods were introduced, making use of tables of solutions for spherical triangles of various dimensions.



190.18

Figure 12-1.—Relationship of circles of equal altitude and intercept "a."



ALTITUDE INTERCEPT "A" IS "TOWARD", AS ALTITUDE OBSERVED IS GREATER THAN COMPUTED.

ALTITUDE INTERCEPT "A" IS "AWAY", AS ALTITUDE OBSERVED IS LESS THAN COMPUTED.

190.19
Figure 12-2.—Plot of LOP.

In this chapter, sight reduction by later and more modern methods will be described, together with the plotting of celestial lines of position and celestial fixes. Preliminary to actual sight reduction, the marine sextant and its use, corrections to sextant altitudes, the use of the Nautical Almanac for finding Greenwich hour angle and declination, and the computation of meridian angle from Greenwich hour angle, will be considered.

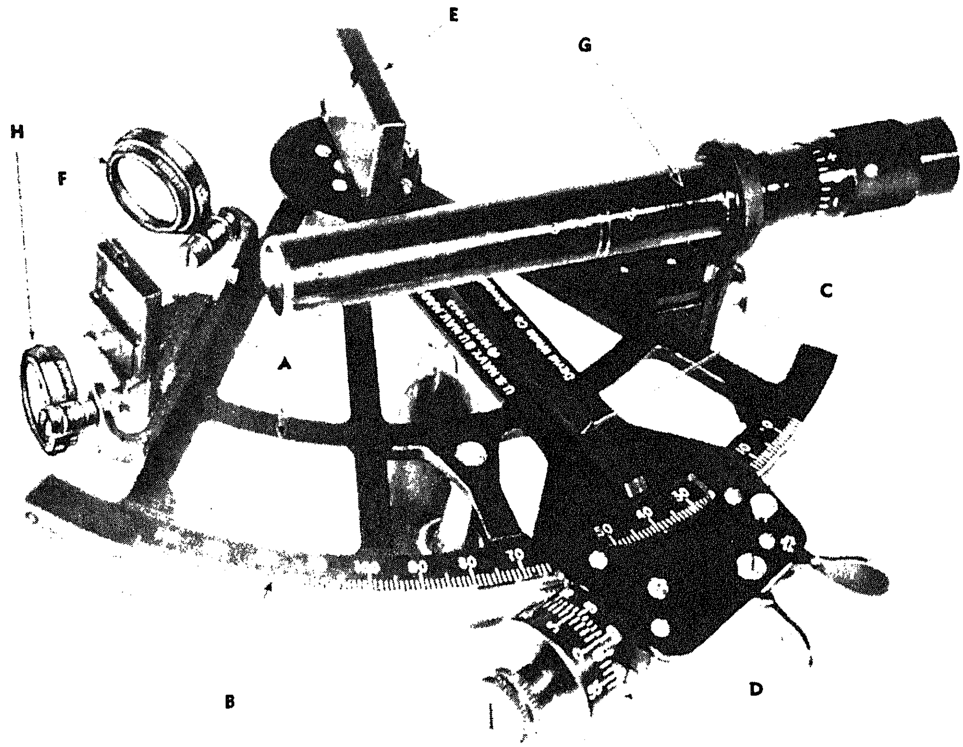
1202. MARINE SEXTANT

Previously introduced in Art. 308, the sextant (figure 12-3) is used to measure altitudes of celestial bodies above the visual horizon. Measurement is effected by bringing into coincidence the images, one direct and one reflected, of the visual horizon and the celestial body. The sextant was so named because its arc represents approximately one-sixth of a circle. Nevertheless, because of its optical principle of double reflection as briefly described herein, the sextant can usually measure twice as much arc, or something greater than a third of a circle. Its optical principle was first described by Sir Isaac Newton and later independently rediscovered in 1731 by Hadley in England and Godfrey in Philadelphia.

The marine sextant consists of the following parts:

A. Frame—Support for other parts.
B. Limb—An arc (approximately 1/6 of a circle) graduated in degrees.
C. Index arm—Arm pivoting from center of curvature; lower end indicates reading on limb and mounts the micrometer drum.
D. Micrometer—Provides a scale for reading minutes and tenths of minutes.
E. Index mirror—Mirror on upper end of index arm which is perpendicular to the plane of the limb.
F. Horizon glass—A glass window, the left half of which is clear glass and the right half a mirror, mounted on frame and parallel to the index mirror at an instrument setting of 0 degrees.
G. Telescope—Inserted in collar attached to frame to magnify field of vision.
H. Index and horizon filters (in some instruments, shades).

The optical principle upon which the sextant is based is that the angle between the first and last direction of a ray of light that has undergone two reflections in the same plane is twice the



29.268(190)
Figure 12-3.— Marine sextant.

angle that the two reflecting surfaces make with each other.

To make a reading with the sextant, set the index arm to 0 degrees. Look through the mirror half of the horizon glass at the celestial body which also appears in the clear glass half. Move the index arm forward slowly, at the same time tilting the instrument forward, until the reflected image is in coincidence with the horizon. Fine adjustment may then be made using the micrometer drum on the index arm. Read altitude in degrees on the limb, read minutes on the forward movable part of the drum at the 0 mark, and read tenths of a minute on the micrometer scale (which makes a 10:9 ratio with the minutes scale).

In observing a star or a planet, bring the center of the star or planet into coincidence with the horizon. In the case of the sun, normally the lower limb (lower edge) is brought into coincidence; however, if the upper limb is more clearly defined, an upper limb shot may be taken if so identified. Moon observations, like sun observations, may be of either limb.

In observing stars, if difficulty is experienced in bringing stars to the horizon, the instrument may be inverted and the index arm moved to bring the horizon up to the celestial body without any tilt of the instrument or movement of the field of vision.

When the horizon is "fuzzy," or indefinite directly beneath a celestial body, the navigator may face the reciprocal of its azimuth and use the sextant to measure the supplement of the altitude. When this is done in the case of the sun or the moon, if a lower limb observation is desired the navigator makes what appears to him to be an upper limb observation, otherwise he must add the sun's (or moon's diameter to the sextant reading.

Before or after observing altitudes with the sextant, the navigator determines index correction, a current error in his instrument. To do this, he sets the instrument on absolute zero and looks through the horizon glass at a distant horizon. If the horizon forms an unbroken line in both halves of the horizon glass, the index correction (abbreviated IC) is 0. If the line is

broken, he should move the micrometer drum until it is straight and read the discrepancy between absolute 0 and the corrected reading. If the corrected drum setting moves the index arm to the right of 0 on the limb, the IC is additive. If the corrected drum setting moves the index arm to the left of 0 on the limb, the IC is subtractive.

If a sextant is in complete adjustment the following will be true:

(a) The index mirror will be perpendicular to the plane of the limb.

(b) The horizon glass will be perpendicular to the plane of the limb.

(c) The horizon glass will be parallel to the index mirror at absolute zero.

(d) The line of sight of the telescope (if used) will be parallel to the plane of the limb.

The index mirror is perpendicular to the plane of the instrument if the limb and its reflection appears in the index glass as an unbroken line. The horizon glass is perpendicular to the plane of the instrument if when tilted and set to 0, the horizon appears as an unbroken line in both halves of the glass. The horizon glass and the index mirror are parallel if at a 0 setting (untilted), the horizon appears as an unbroken line in both halves. To adjust, two set screws are associated with each mirror. Always slack off on one set screw before tightening its mate. In addition to the mirrors, the collar of the telescope should be adjusted if the extended line of sight (axis of the telescope) diverges from the extended plane of the instrument.

Sextants are equipped with colored filters or shades for sun observations; these lenses protect the navigator's eyes from the bright rays of the sun.

An excellent marine sextant used today is known generally as the endless tangent screw sextant.

1203. CORRECTING SEXTANT ALTITUDES

The altitude of a celestial body as observed by a navigator does not necessarily correspond to the altitude measured from the celestial horizon. To differentiate, we abbreviate sextant altitude as Hs and observed altitude as Ho. Sextant altitude (Hs) is corrected or converted to Ho by applying corrections for the following:

INDEX CORRECTION (IC).—A correction peculiar to an individual instrument and change able in value. May be a plus or minus correction.

DIP (D).—The horizon from which measurement is referenced depends upon the altitude (height above sea level of the observer); at higher altitudes the horizon is at a greater distance and sextant altitude will read in excess of altitude based upon the true celestial horizon. Dip is always a minus correction and increases with the height from which the observation is made.

REFRACTION (R).—When the rays of light pass from a less dense medium (space) to a more dense medium (earth's atmosphere), they are bent toward the vertical, resulting in the celestial body appearing higher than its actual position. Refraction error is maximum at low altitudes, making observations of bodies having altitudes less than 10 degrees less reliable; the error decreases at higher altitudes, and is zero at an altitude of 90°. The correction for refraction is always a minus correction.

AIR TEMPERATURE—ATMOSPHERIC PRESSURE (TB).—An additional correction for refraction due to nonstandard atmospheric conditions. May be a positive or negative correction.

PARALLAX (P).—The center of the earth is considered to be the center of the celestial sphere. For all bodies beyond our solar system, the distance is so great as compared to the radius of the earth that the latter is of no consequence. In the case of bodies within our solar system, their distance is not so great when compared to the earth's radius and we must take into account the earth's radius to reduce the sight to the altitude as measured from the center of the earth. Parallax at altitude 0° is called horizontal parallax (HP). Parallax is always a plus correction, and is maximum at altitude 0°.

SEMIDIAMETER (SD).—Tabulated Astronomical data is normally based upon the center of celestial bodies. However, it is not practicable to measure the altitude to the center of either the sun or the moon as their diameters are wider and their centers do not afford a definite reference for measurement. Accordingly, all measurements are made to either the upper limb (upper edge) or lower limb (lower edge), abbreviated UL and LL respectively, and the

semidiameter is subtracted or added as appropriate. Also, tables may be compiled so that semidiameter is always a plus correction. Whether the upper limb or the lower limb of the sun or moon is used depends upon which limb is most clearly defined.

AUGMENTATION (A).—An increase in the semidiameter of the moon which increases with altitude. Correction has the same sign as the semidiameter.

IRRADIATION (J).—Correction for the expansion of the upper limb of the sun and the contraction of the horizon because of optical illusion. Always a negative correction.

PHASE (F).—A correction for compensation for the difference between the apparent and actual centers of the planets Venus and Mars. It may be positive or negative.

These corrections may be summarized as shown in Table 12-1, the letters "NA" signifying "Nautical Almanac." Corrections (1) and (2) for instrument error and height of eye (dip) are applied to the sextant altitude (Hs) to determine the apparent altitude (Ha), which in turn is used as the argument for entry in the other tables by which corrections (3) and (4) are computed. However, for simplification of computations, Ha is generally computed mentally and all corrections are totaled and applied to Hs to find Ho.

Note 1:

In tables A-2 and A-3 for the sun, separate corrections are given for "Oct. - Mar." and "Apr. - Sept."

Table 12-1.—Corrections to sextant altitudes

Correction	Applies to	Found	Corrects	+ or -	Notes
(1) Index	All sights	Sextant	IC	Either	
(2) Height of eye	All sights	NA, Table A-2 and inside of back cover	D	Minus	
(3) Altitude	Stars & Planets	NA, Tables A-2, A-3	R	Minus	
	Sun	NA, Tables A-2, A-3	R, P & S.D.	+(LL) -(UL)	See Note 1
	Moon	NA, Inside back cover	R, P A & S.D. (Standard values)	Plus	See Note 2
(4) Additional	All sights	NA, Table A-4	TB	Either	
	Venus & Mars	NA, Table A-2	P, F	Plus	See Note 3
	Moon	NA, Inside back cover	P	Plus	See Note 2

190.21

Note 2:

The altitude and additional corrections for the moon are to be added regardless of which limb is observed, but 30' must be subtracted from the apparent altitude in an upper limb observation. Horizontal parallax (HP) is taken from the daily page of the NA for use as argument for entry in the table for the additional alt. corr.

Note 3:

The correction in table A-2 for Venus applies only when the sun is below the horizon. (For daylight observation of Venus, parallax and phase are computed directly using the formula p cos H - k cos Ø, where H is the altitude, Ø is the angle of the planet between the vertical and the sun, and p and k are functions for parallax and phase related to dates, and recorded in the explanation pages in the back of the Nautical Almanac.) In actual practice, the additional computation for a daylight observation of Venus can be omitted.

EXAMPLE 1:

Given: Hs of the sun (lower limb) is 69-18.7' on 1 Jan 1970. Height of eye is 64 feet. IC is plus 1.5'. Standard atmospheric conditions.

Required: Ho.

Solution:

Corrections	Plus	Minus
IC	1.5	
HE		7.8
Alt.	15.8	
Sum	+17.3	-7.8
	-7.8	
	+9.5	
Hs	69-18.7'	
Ho	69-28.2	

Note: There is no additional correction for the sun from Table A-4 because the altitude exceeded 50°.

EXAMPLE 2:

Given: Hs of Venus is 17-10.5' on 2 Jan. 1970. Twilight observation. Height of eye is 37 feet. IC is -1.0'. Temp. 62°F, Bar. pressure 30.00 in.

Required: Ho.

Solution:

Corrections	Plus	Minus
IC		1.0
HE		5.9
Alt.		3.1
Add.	0.2*	
Sum	+0.2	-10.0
		+0.2
		-9.8
	Hs	17-10.5
	Ho	17-00.7

*0.1 From Table A-2,
0.1 From Table A-4.

EXAMPLE 3:

Given: Hs of the moon's lower limb is 26-19.5' at 1200 GMT on 3 Jan 1970. Height of eye is 49 feet. IC is plus 2.0'. Barometric pressure and temperature normal.

Required: Ho.

Solution:

Corrections	Plus	Minus
IC	2.0	
HE		6.8
Alt.	60.4	
Add.	5.6*	
Sum	+68.0	-6.8
	-6.8	
	+61.2	
Hs	26-19.5'	
Ho	27-20.7	

*H.P. From Daily Page is 58.2

Note: Had this been an observation of the upper limb, an additional -30' correction would have been applied.

EXAMPLE 4:

Given: Hs of Capella is 54-10.5'. Height of eye is 30 feet. IC is 0.0.

Required: Ho.

Solution:

Corrections	Plus	Minus
HE		5.3
Alt.		0.7
		-6.0
Hs		54-10.5'
Ho		54-04.5'

1204. FINDING GREENWICH HOUR ANGLE AND MERIDIAN ANGLE

The Nautical Almanac tabulates:

a. For each hour of GMT, the GHA of the first point of Aries, navigational planets, sun, and moon.

b. The SHA's by dates for all navigational stars.

c. Additional increments of GHA for minutes and seconds elapsed after the hour.

The first step in finding meridian angle "t" is the computation of GHA which is accomplished as follows:

SUN.—Using GMT, and Greenwich date of observation, enter Nautical Almanac and record tabulated hourly value of GHA. Turn to the yellow pages of the Nautical Almanac, and entering with the minutes and seconds after the hour, find the increase in the sun's GHA since the last tabulated (hourly) value. Add the tabulated value and the increase for elapsed minutes and seconds.

MOON AND PLANETS.—Proceed as with the sun, but record a code value identified as "v" together with sign which appears at the foot of the GHA sub-column for planets, and to the right of each tabulated GHA for the moon. Find the sum of the hourly value and the minute-second increment, as in the case of the sun, but using column headed "moon" or "sun-planets" as appropriate, then apply a code correction according to the sign of the code. This code correction is found in the yellow pages of the Nautical Almanac, entering with minutes elapsed since beginning of hour, and the code. The code correction is always plus for GHA except in the case of the inferior planet Venus, which has an orbit inside the earth's orbit. Its apparent motion westward, as compared with the sun's motion, shows that Venus has a numerically lesser, relative speed; when its correction should be subtracted, the code letter "v" will be prefixed by a minus sign. The purpose of the code correction is to simplify interpolation and to keep tabulated values at a minimum. For the planets, the code correction makes possible the use of the GHA value for minutes and seconds as tabulated for the sun.

STARS.—Determine the SHA from the daily page, entering with the star name and Greenwich date. Find the GHA of ♈ in the same manner as used to find the GHA of the sun (except that in the yellow pages a separate column is provided for ♈). Adding the GHA of ♈ and the SHA of the star we find the GHA of the star.

A code correction is never used in connection with the sun's GHA, the GHA of ♈, or the SHA of a star. To convert GHA to LHA, and LHA to meridian angle (t), the following relationships, as developed in art. 1004, are used:

LHA = GHA − Wλ
LHA = GHA + Eλ
GHA* = GHA♈ + SHA*
LHA > 180, t = 360 − LHA, and t is east.
LHA < 180, t = LHA, and t is west.

The following examples illustrate the complete problem of finding GHA and "t":

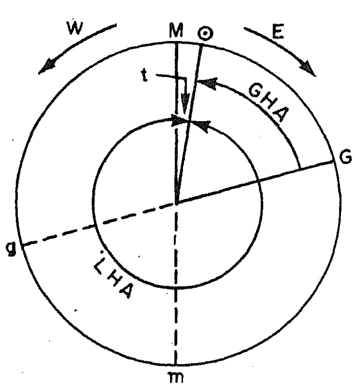
EXAMPLE 1:

Given: 1 Jan. 1970, ZT 11-18-45, Long. 71-30 W.

Required: GHA and t of sun.

Solution:

ZT	11-18-45	1 Jan.	
ZD	+5	(71-30/15)	
GMT	16-18-45	1 Jan.	
GHA (16 hrs.)		59-06.0	
Min-sec (18-45)		4-41.3	
GHA of sun		63-47.3 or	423-47.3
Long.			-71-30.0 W.
LHA			352-17.3
t = 360 - LHA or			7-42.7 E.



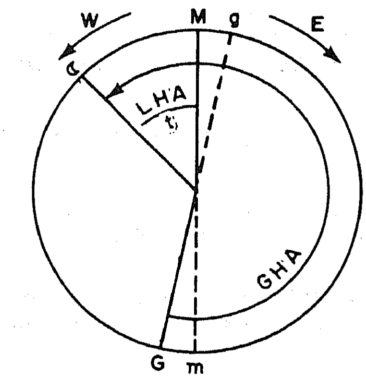
XAMPLE 2:

iven: 2 Jan. 1970, ZT 09-19-55, Long. 169-15 E.

equired: GHA and t of moon.

lution:

ZT	09-19-55	2 Jan.
ZD	-11	(169-15/15)
GMT	22-19-55	1 Jan.
GHA (22 hrs.)		231-39.4 (13.8)
Min-sec (19-55)		4-45.1
Code Corr.		4.5
GHA of Moon		236-29.0
Long.		+169-15.0 E.
		405-44.0
		-360-00.0
LHA		45-44.0
t = LHA or		45-44.0 W.



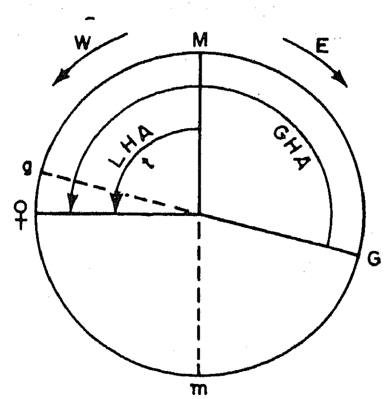
XAMPLE 3:

ven: 2 Jan. 1970, ZT 18-20-00, Long. 110-10 W.

equired: GHA and t of Venus.

lution:

ZT	18-20-00	2 Jan.
ZD	+7	(104-10/15)
GMT	01-20-00	3 Jan.
GHA	(01 hr.)	199-34.6 (1.0)
Min-sec (20 min)		5-00.0
Code Corr.		- 0.3
GHA of Venus		204-34.3
Long.		110-10.0 W.
LHA		94-24.3
t = LHA or		94-24.3 W.



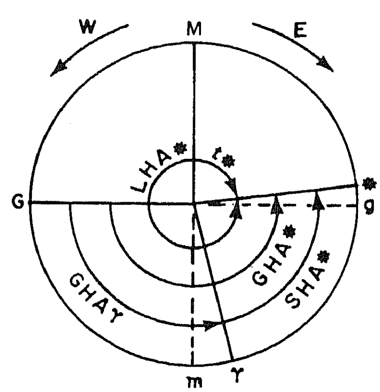
XAMPLE 4:

ven: 3 Jan. 1970, ZT 06-00-00, Long. 92-00 E.

quired: GHA and t of Vega.

lution: Using star name, enter SHA table on daily page; SHA is 81-01.6. Find GHA of Aries.

ZT	06-00-00	3 Jan.
ZD	-6	(92-00/15).
GMT	00-00-00	3 Jan.
GHA♈ (00 hrs.)		102-12.1
SHA of Vega		81-01.6
GHA of Vega		183-13.7
Long.		+92-00.0 E.
LHA		275-13.7
t = 360 - LHA or		84-46.3 E.



In the actual practice of sight reduction, an "assumed longitude" is used in lieu of the "actual longitude." This procedure simplifies subsequent computation as it permits the assumption of a longitude which, when combined with the GHA, results in a local hour angle, and a meridian angle, in even degrees. For example, in west longitude, the longitude assumed should include precisely the same number of minutes (and tenths of minutes) as the GHA; upon subtracting the assumed longitude the remaining local hour angle will result accordingly in even degrees. In east longitude, the longitude assumed should include the number of minutes (and tenths) which when added to the GHA will also result in a local hour angle, and "t," in even degrees. In using this procedure, a longitude should be assumed within 30' of the navigator's best estimate of his position.

1205. FINDING DECLINATION

The Nautical Almanac tabulates declination for the sun, moon, and navigational planets for each hour of GMT. At the foot of each declination sub-column which applies to the sun or planets, a code may be found which is useful for interpolation for any number of minutes. The code follows each tabulated declination of the moon, since the moon's declination changes rapidly as compared to the declination of the sun and planets. To find the change in declination for a part of an hour, enter the yellow pages with the number of minutes and the code. The tabulated declination is prefixed by either an N or S, indicating north or south declination, respectively; the sign of the code correction for elapsed minutes must be determined by inspection of the declination column, noting if declination is increasing or decreasing, between the two hours in question. Combine the tabulated declination and the code correction and label the result with "north" or "south" as appropriate.

To find the tabulated declination of a star, enter the daily page with the star name and Greenwich date. No code correction is necessary since the declination is relatively constant and can not be expected to change within any 3 day period.

EXAMPLE 1:

Given:	GMT 11-18-45	2 Jan. 1970.
Required:	Declination of the sun.	
Solution:	Declination (11 hrs.)	S 22-56.1 (0.2)
	Code Correction	-0.1
	Declination	22-56.0 South

EXAMPLE 2:

Given:	GMT 18-19-25	1 Jan. 1970.
Required:	Declination of the moon.	
Solution:	Declination (18 hrs.)	S 10-41.3 (14.3)
	Code Correction	+4.6
	Declination	10-45.9 South

EXAMPLE 3:

Given:	GMT 05-18-26	3 Jan. 1970.
Required:	Declination of Saturn.	
Solution:	Declination (5 hrs.)	N 9-49.8 (0.0)
	Declination	9-49.8 North

EXAMPLE 4:

Given:	2 Jan. 1970.
Required:	Declination of Dubhe.
Solution:	Tabulated declination of Dubhe is 61-54.5 North on 2 Jan. 1970.

In most celestial computations, GHA and declination are determined concurrently rather than separately, thereby saving time in obtaining vital data from the almanac.

1206. GHA AND DECLINATION BY AIR ALMANAC

The Air Almanac, as introduced in Art. 412, may also be used for the determination of GHA and declination. Issued thrice annually, each volume tabulates data for a four month period. Based upon GMT, the daily pages tabulates the GHA and declination of the sun, moon, Venus, Mars, Jupiter, and Aries at ten minute intervals.

To determine GHA and declination of the sun, the planets, and the moon, enter the Air Almanac with the GMT, nearest and prior to, the actual GMT. The declination tabulated requires no incremental correction. The GHA, however, will normally require an incremental correction, tabulated for minutes and seconds on the inside front cover; one column provides the correction for the sun and the planets, (and for Aries), and a separate column provides for the moon. If a precision of 0.1' is desired for the GHA of the sun (or for Aries), special tables in the back of the Air Almanac should be used. The incremental corrections are always additive.

To find the GHA of a star, the GHA of Aries must be determined, and added to the SHA of that star. The GHA of Aries is found by using the same procedure as in the case of the sun. The SHA of a star, and its declination, is found in the inside front cover of the Almanac, tabulated to the nearest minute for a four month period. If greater precision is desired, separate tables

provide such by month for SHA and declination to an accuracy of 0.1' in the back of the Air Almanac.

The Air Almanac, although less precise than the Nautical Almanac, may be used in the correction of sextant altitudes.

1207. SOLUTION OF THE ASTRONOMICAL TRIANGLE BY H.O. 214

There are several methods for solving the astronomical triangle, and each method has certain advantages over the others. However, for combined accuracy, completeness, convenience, and availability, the method that makes use of Tables of Computed Altitude and Azimuth (H.O. 214) has been generally preferred. H.O. 214 consists of nine volumes, one for each 10 degrees of latitude. Each volume is divided into sections, each section tabulating solutions for a single degree of latitude. Vertical columns within a section are headed by declination values, usually at intervals of 30'. On the left hand page, solutions are for cases in which latitude and declination are of the same name. On the right hand page, solutions are usually for cases in which latitude and declination are of contrary names; however, when it is possible for meridian angle to exceed 90 degrees with declination and latitude being of the same name, the left hand page tabulations may be continued on the right hand page and so identified. Horizontal lines are labeled with meridian angle, identified not as "t" but as H.A., with each line or entry being 1 degree apart. Against meridian angle, declination, and latitude, the tabulated altitude (Ht) and azimuth angle (Z), identified as "Alt" and "Az" respectively, are given. H.O. 214 then affords solutions for all possible astronomical triangles except those based upon certain circumpolar stars having declinations extremely high and not tabulated. Solutions by other methods, H.O. 249, H.O. 229, and H.O. 211, are briefly described in Articles 1209-1211.

A logical approach to the solution for a line of position would be to locate the GP (geographic position) by GHA and declination, and using the GP as center, draw a circle with a radius equal to the co-alt in degrees multiplied by 60 (co-alt in minutes or miles), thus arriving at our locus of position (called a circle of equal altitude). Since the distance of an observer from the GP is a function of the altitude of the star, the altitude would remain constant for a ship traveling in a circle having the GP as center; as the radius increased, the altitude would decrease, and as the radius decreased, the altitude would increase. Since two circles may intersect at two points, two positions are possible as the result of two observations. However, the correct position could be chosen by considering the azimuth.

The plot of circles of equal altitude is impractical since the navigator for greater accuracy uses a large scale chart depicting an area too small to accommodate a plot containing both the GP's and the points of intersection of circles of equal altitude. For this reason, in our H.O. 214 solution, we plot an assumed position (AP), and for that position solve for the altitude and azimuth for a given time. The computed altitude (Hc) is the altitude which would be observed if the navigator had been at the assumed position at the given time, and the complement of the computed altitude, converted to nautical miles, is the distance to the GP from the assumed position, measured along the azimuth. The observed altitude thus locates the circle of equal altitude which is the observer's locus of position. The difference between the computed altitude (Hc) and the observed altitude (Ho) is the distance between the assumed and the actual circles of equal altitude and is called altitude difference or intercept, abbreviated "a."

If Hc is greater than Ho, intercept is labeled "away" because the actual position is at a greater distance from the GP than the assumed position. Conversely, if the Hc is less than the Ho, the intercept is labeled "toward" because the actual position is nearer the GP than the assumed position. A thumb rule is "Coast Guard Academy" meaning "computed greater away." See figure 12-1.

To plot a line of position, using the altitude intercept method as introduced in Art. 1201, locate and plot the AP; through the AP plot the azimuth line. Along the azimuth, measure a distance equal to the intercept. This is measured from the AP, along the azimuth in the direction of the GP if "toward," and the reciprocal of the azimuth (away from GP) if "away." At the point on the azimuth line established by the intercept, erect a perpendicular to the azimuth line; this perpendicular is a celestial line of position, and the intersection of two or more such lines of position will provide a celestial fix. The LOP is labeled with the time expressed in four digits above the line and the name or symbol of the celestial body below the line. See figure 12-2.

The Nautical Almanac is generally used in conjunction with the appropriate volume of H.O.

214 to compute intercept and azimuth. The steps in the solution are:

a. Correct Hs, and determine Ho.

b. Apply zone description to zone time of sight and local date to find the Greenwich mean time and Greenwich date.

c. With GMT, enter the Nautical Almanac and compute GHA.

d. With GMT, enter the Nautical Almanac and compute declination.

e. Assume a longitude which, when applied to the GHA (added if east longitude and subtracted if west longitude), results in a LHA in even degrees. This will later make it unnecessary to interpolate for t.

f. From LHA, compute t.

g. Assume a latitude in even degrees to make it unnecessary to interpolate for latitude. When assuming latitude and longitude, the assumed position should be within 30 minutes of the estimated or DR position.

h. Enter H.O. 214 with t, dec. (to the nearest tabulated value), and assumed latitude. Record the tabulated altitude (Ht), and the azimuth angle (Z). To interpolate altitude for declination difference, record the interpolation factor known as Δd which immediately follows the tabulated altitude. Note the value of Ht in the adjoining declination column having a declination value which is second nearest to the actual declination. If the previously recorded Ht is the least of the two values, the Δd is a plus value; if the previously recorded Ht is the greater of the two values, the Δd is a minus value. Multiply the Δd value, which is in hundredths, by the difference between the actual and the tabulated declination with which H.O. 214 was entered (in minutes and tenths of minutes) to find the correction to tabulated altitude (Ht). This may be expedited by using a self explanatory multiplication table in the inside back cover of each volume of H.O. 214. Apply the correction (according to the sign of Δd) to Ht. This will provide the computed altitude (Hc); numerically, the value of Hc will lie between the Ht's of the two declination columns which are nearest and "bracket" the actual declination. In sight reduction, it is not necessary to interpolate azimuth angle for declination difference.

i. Compare Hc and Ho. Compute intercept by subtracting the lesser from the greater. Label intercept as toward (T) or away (A).

j. Label azimuth angle making the prefix the sign of the elevated pole (latitude) and the suffix the sign of the meridian angle. From azimuth angle, compute and record azimuth (Zn).

Summarized, the solution for a line of position is as follows:

a. Enter Nautical Almanac with:
   (1) Hs of celestial body.
   (2) IC of sextant.
   (3) Height of eye.
   (4) DR or estimated position.
   (5) Zone time, zone description, and date.

b. Compute, and enter H.O. 214 with:
   (1) Meridian angle (t).
   (2) Declination (dec).
   (3) Assumed latitude.

c. Compute and use in conjunction with assumed position to plot LOP:
   (1) True azimuth (Zn).
   (2) Intercept (a).

d. Steps in plotting:
   (1) Plot AP.
   (2) Plot Zn through AP.
   (3) Measure intercept from AP along Zn in proper direction.
   (4) Erect a perpendicular to Zn at the altitude intercept distance from AP.
   (5) Label perpendicular as a celestial line of position.

If it is apparent that an error has been made, Appendix H, which contains the mechanics of error finding, may be consulted.

EXAMPLES OF SOLUTIONS

EXAMPLE 1:

Sun (LL). Hs 24°-46.8, IC -1.0, HE 36 ft., Lat. 35-25 N. Long. 77-42 W. at ZT 14-18-10 1 Jan. 1970. Temp. 35°F, Bar. Press. 30.25".

EXAMPLE 2:

Venus. Hs 32°-48.2, IC +1.8, HE 35 ft., Lat. 32-40 N. Long. 51-15 W. at ZT 11-19-28 on 1 Jan. 1970. Temp. 50°F., Bar. Press. 29.80". Daylight observation.

EXAMPLE 3:

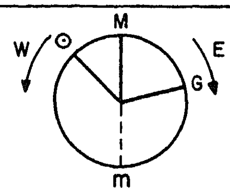
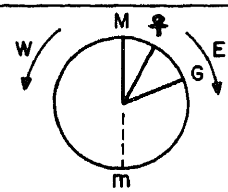
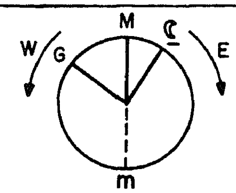
Moon (LL). Hs 66°-38.3', IC -2.0, HE 60 ft., Lat. 35-10 S. Long. 59-38 E. at ZT 06-18-30 2 Jan. 1970. Temp. and pressure normal.

EXAMPLE 4:

Peacock. Hs 42°-39.6', IC -1.5, HE 20 ft., Lat. 36-18 S. Long. 82-03 W. at ZT 18-18-05 3 Jan. 1970. Temp. and pressure normal.

For solutions to examples 1 to 3, see the following page, a typical, multiple sight form. Example 4 next following is a typical, single sight form. Appendix I contains an alternate sight form example.

SOLUTIONS FOR EXAMPLES 1, 2, AND 3.

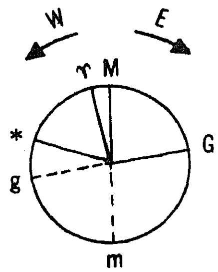
DR POSIT	Lat. 35-25 N Long. 77-42 W 1 Jan		Lat. 32-40 N Long. 51-15 W 1 Jan		Lat. 35-10 S Long. 59-38 E 2 Jan	
TIME DIAGRAMS	 		 		 	
BODY	SUN (LL)		VENUS		MOON (LL)	
	Plus	Minus	Plus	Minus	Plus	Minus
I.C. H.E. Corr. Add'l	 14.2 	1.0 5.8 0.1	**1.8** 	 5.7 1.5 	 33.2 4.3	2.0 7.5
Totals	14.2	6.9	1.8	7.2	37.5	9.5
Hs Corr.	24-46.8 +7.3		32-48.2 -5.4		66-38.3 +28.0	
Ho	24-54.1		32-42.8		67-06.3	
WT WE	This space may be used to convert watch time to zone time by the application of watch error					
ZT ZD	14-18-10 +5		11-19-28 +3		06-18-30 -4	
GMT Date	19-18-10 1 Jan 1970		14-19-28 1 Jan 1970		02-18-30 2 Jan 1970	
GHA(hours) min/sec Code Corr. SHA(Stars)	104-05.2 4-32.5 		35-08.6 4-52.0 (-1.0)-0.3 360-00.0		289-50.0 4-24.9 (+13.4) 4.1 	
Total GHA a Long.	108-37.7 77-37.7W		400-00.3 51-00.3W		294-19.0 59-41.0E	
LHA t	31 31W		349 11E		354 6E	
Dec. Tab. Code Corr.	**(-0.2)** 22-59.6S -0.1		(-0.1) 23-37.6S 0.0		(+14.0) 12-34.8S +4.3	
Dec.	22-59.5S		23-37.6S		12-39.1S	
Enter Dec. H.O. t 214 a Lat.	23-00.0S 31W 35N		23-30.0S 11E 33N		12-30.0S 6E 35S	
 Ht Corr.	d diff 0.5 **Δd** +88 24-58.4 +0.4		d diff 7.6 **Δd** -99 32-32.1 -7.5		d diff 9.1 **Δd** +98 66-51.2 +8.9	
Hc Ho	24-58.8 24-54.1		32-24.6 32-42.8		67-00.1 67-06.3	
a Z Zn	4.7 A N 148.5 W 211.5(T)		18.2 T N 168.0 E 168.0(T)		6.2 T S 165 E 015 (T)	
Advance*						

* See Art. 1208

SOLUTION FOR EXAMPLE 4

BODY: Peacock
DATE: 3 Jan 1970
DR POSIT: LAT. 36-18S
LONG. 82-03W

	+	-	
I.C.		1.5	
H.E.		4.3	
CORR.		1.1	
		-6.9	
Hs		42 - 39.6	
Ho		42 - 32.7	
ZT	18-18-05		
ZD	+5		
GMT	23-18-05		3 JAN
GHA ♈		88 - 08.8	
M-S CORR		4 - 32.0	
SHA*		54 - 11.1	
GHA*		146 - 51.9	
a. Long.		81 - 51.9W	
LHA		65	



t	65W	
dec.	56-50.2S	
a. Lat.	36S	
Ht	42-46.7	(-05)
CORR	-0.5	
Hc	42-46.2	
Ho	42-32.7	
a	13.5A	
Z	S042.3W	
Zn	222.3	

1208. PLOTTING THE CELESTIAL FIX

In celestial navigation, lines of position are rarely obtained simultaneously; this is especially true during the day when the sun may be the only available celestial body. A celestial line of position may be advanced for 3 or 4 hours, if necessary to obtain a celestial running fix (fig. 12-4) in the same manner as described in chapter 7. It may also be advanced by advancing the AP in direction and distance an amount consistent with the ship's travel during the interval between two successive observations. In the latter procedure, the azimuth line is drawn through the advanced AP without any change in direction; the advanced LOP is drawn perpendicular to the azimuth, a distance from the AP equal to the intercept, and toward or away from the GP as appropriate.

At morning and evening twilight, the navigator may succeed in observing the altitudes of a number of celestial bodies in a few minutes and thus establish a celestial fix. If 2 or more minutes elapse between observations, the navigator must consider:

a. elapsed time;
b. speed of ship; and
c. scale of the chart or plotting sheet;

to determine whether or not a more accurate fix can be obtained by advancing AP's to a common time. It is possible during the day to obtain a celestial fix rather than a celestial running fix if two or more of the three following bodies are visible:

a. sun;
b. moon;
c. Venus.

EXAMPLE 1—Star plotting problem (fig. 12-5):

Given: The 0635 DR position of your ship is Lat. 36 N., Long. 120W. Between 0600 and 0700 your course is 000 (T), speed 20 knots. At morning twilight, you observe available stars and through computations obtain the following data:

Time	Body	a Lat	a Long	Advance*	Zn	a
0610	Vega	36N	120-36W	8.3	025	6.0T
0620	Peacock	36N	119-55W	5.0	100	24.0A
0635	Canopus	36N	120-20W	Base	330	10.3T

* Computation of advance is necessary because the stars were not observed simultaneously, and to fix our position, we must use a common time (preferable method is to choose as a common time the time of the last sight). To use a common time we adjust our AP's, except in the case of the AP of the star observed at the common time (in this problem, Canopus, which is considered the base star). Advance is computed as follows:

Body	Time	Speed	Distance of Advance
Vega	0635-0610 = 25 min.	20 kts.	8.3 mi.
Peacock	0635-0620 = 15 min.	20 kts.	5.0 mi.

Required: Plot the 0635 fix.

Solution:
a. Label plotting sheet with center meridian as 120 W.
b. Plot 0635 DR.
c. Plot AP's of Vega. Peacock, and Canopus, using assumed latitude and longitude. Label AP's.
d. Advance AP Vega in direction 000 a distance of 8.3 mi. Advance AP Peacock in direction 000 a distance of 5.0 mi. Erase old AP's of Vega and Peacock, if desired.
e. Plot azimuths, intercepts, and LOP's. Label LOP's and fix.

NOTE: If the reason for advancement of earlier AP's is not clear, then the following exercise should be completed:

a. Plot AP's of Vega, Peacock, and Canopus using assumed latitude and longitude. Label AP's.

b. Plot azimuths, intercepts, and LOP's. Label LOP's.

c. Advance LOP Vega and LOP Peacock in direction 000, in accordance with the procedure in plotting running fixes in piloting.

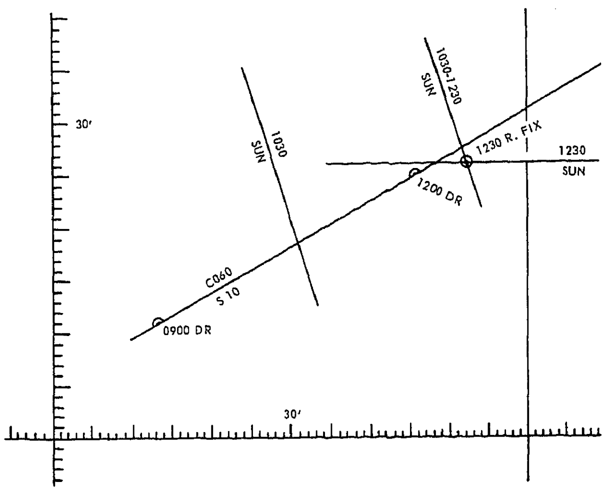
d. Check latitude and longitude of fix against coordinates obtained in previous method of solution.

ANSWER: Lat. 36-10.5 N; Long. 120-23.0 W.

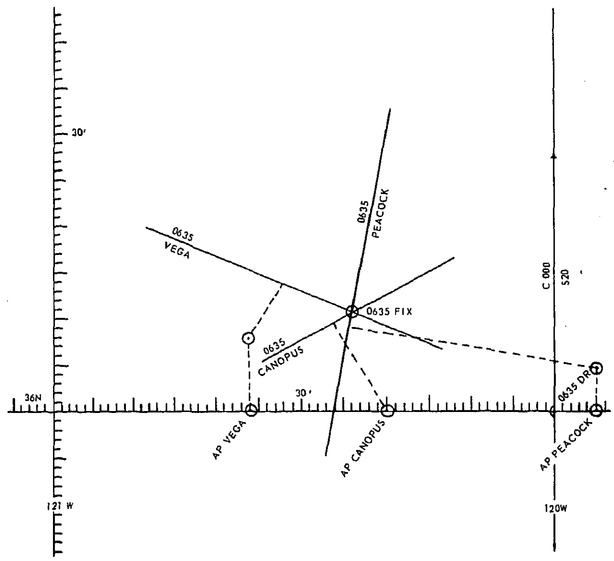
1209. SIGHT REDUCTION BY H.O. 249

Designed for aerial use, Sight Reduction Tables for Air Navigation (H.O. 249) are useful in both air and surface navigation, when in the latter case, somewhat less precision is acceptable. See Appendix I. These tables, similar to H.O. 214, consist of three volumes. The first volume is used for seven stars, selected on the basis of azimuth, declination, hour angle, and magnitude, and to provide such distribution or continuity as to be generally useful worldwide. Volume I differs from H.O. 214 in that the arguments for entry are the LHA♈ and the name of the star, rather than meridian angle, declination and assumed latitude; it also differs in that altitudes and azimuths are recorded to the nearest minute and nearest degree respectively. Additionally, and more conveniently, Volume I tabulates the true azimuth (Zn) rather than azimuth angle (Z).

Volumes II and III have greater similarity to H.O. 214 than to Volume I. Volume II provides altitude and azimuth solutions for latitudes



190.20
Figure 12-4.—Celestial running fix.



69.75
Figure 12-5.—Star fix.

0° to 39°; Volume III provides for latitudes 40° to 89°. These two volumes provide for bodies having declinations as great as 29°, and thus are useful in sight reduction of all bodies within the solar system and for stars having a declination of 29° or less. Entering arguments are latitude, declination of same or contrary name, and LHA, all to the nearest degree. Longitude is assumed so as to provide an even degree of LHA. Unlike Volume I, Volumes II and III record azimuth angle (Z) rather than true azimuth (Zn). Inasmuch as these tables are designed primarily for aviation use, LHAs are included for stars with a negative altitude as might be visible from an aircraft.

In all volumes of H.O. 249, whenever the declination is not an even degree, as is the usual case, the next lower declination column is used; to correct the tabulated altitude for the declination difference, a factor called "d," recorded after each tabulated altitude, must be multiplied by the declination difference, and applied according to sign to the tabulated altitude. Multiplication tables are conveniently located in the back of each volume for determining this correction.

1210. SIGHT REDUCTION BY H.O. 229

Sight Reduction Tables for Marine Navigation (H.O. 229) is the marine or surface counterpart of H.O. 249 and will eventually supersede H.O. 214. See Appendix J. It is issued in six volumes, with one volume for each 15° band of latitude. Each volume is divided into two sections, based upon latitude, and contains tabulated altitudes and azimuths for 16° of latitude. For example, the two sections of Volume I are applicable to latitudes of 0° to 7° and 8° to 15° respectively; data pertaining to 15° latitude is also contained at the beginning of the first section of Volume II. An accuracy of 0.1' for altitude and 0.1° for azimuth angle may be attained in calculations through the use of applicable corrections to the tabulated data.

Entering arguments are latitude, declination, and local hour angle, all in whole degrees. Although H.O. 229 provides for entry with the exact DR latitude, the tables are intended to be entered with an assumed latitude of the nearest whole degree, and an assumed longitude which will result in a local hour angle of an integral degree. The local hour angle determines the page of entry, upon which altitude and azimuth data is tabulated in columns headed by latitude entries; vertical columns on the right and left margins of each page provides for the declination entry. For each entry of LHA, the left hand page provides tabulations for latitude and declination of the same name. The right-hand page, upper portion, provides for latitude and declination of contrary name; the lower portion of the right-hand page is a continuation of the page to the left, and contains tabulations

for latitude and declination of the same name, as applicable to values of LHA in excess of 90° but less than 270°.

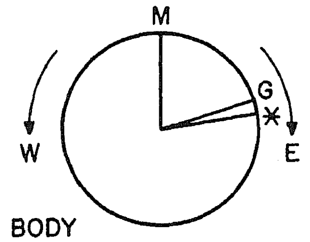
As in the use of H.O. 249, the declination entry is the nearest tabulated value which is equal to or numerically less than the actual declination. To the right of each tabulated altitude, under a column sub-headed as "d," is the incremental change in altitude based upon a declination increase of one degree, together with sign. An interpolation table is conveniently included, and is entered with the declination increase (difference between the actual declination and the declination integer used as an argument of entry) and the altitude difference (d). The interpolation table is entered in two steps. In the first, the declination increase, and even tens of minutes of altitude difference (d), are used; in the second, the declination increase, and the remaining altitude difference (d) in minutes and tenths of minutes, are used to find the correction to altitude. In this step, decimals (tenths) may be found as a vertical argument. Values found in these two steps are combined and applied to the tabulated altitude in accordance with the sign of altitude difference (d). This is the first of two procedures known as difference corrections.

For greater precision, a second difference correction is sometimes appropriate. When this is the case, the value of "d" is printed in H.O. 229 in italics and is followed by a dot. The second difference is found by comparing the altitude differences above and below the base value; for example, if the declination argument for entry is 20°, the altitude difference values for 19° and 21° are compared, and the difference between the two is the double second difference. Interpolation tables contain, on their right-hand edge, a double column which is identified as a double second difference and correction column; this a critical table and correction values are taken therefrom directly. The second difference correction is always additive. As appropriate, first and second difference corrections are thusly obtained, combined, and applied to the tabulated altitude to determine computed altitude.

H.O. 229 tabulates, following altitude difference (d), the azimuth angle (Z) to the nearest tenth of a degree. For greater accuracy, mental interpolation may be used, not only to correct the azimuth angle for the declination increase or difference, but also for differences in latitude and LHA. Rules are given on each page of H.O. 229 for conversion of azimuth angle (Z) to true azimuth (Zn).

The following sight reduction for the star Aldebaran illustrates the use of H.O. 229.

Local Date 2 JAN 1970
Course 060°
Speed 15 kts
Body Aldebaran



DR:	Lat	34	15N	
	Long	63	45W	
ZT		1740-19		
ZD		+4		
GMT		2140-19		
Gr Date		2 JAN		
GHA (hrs)		57	04.7	
GHA (m & s)		10	06.4	
v corr or SHA		291	26.7	
Total GHA		358	37.8	
a Long		63	37.8	E (W)
LHA		295		
Dec Tab		16	27.2	(N) S
d. corr (±)		( )		
Total Dec.		16	27.2	(N) S
Enter H.O. 229	LHA	295		
	Dec	16		(N) S
	a Lat	34		(N) S
Dec Inc	(±) d	27.2	30.1	
tens	DS diff	30	13.6	
units	DS corr	.1	+00	
Total corr (±)			13.6	
Hc (tab Alt)		29	24.1	
HC		29	37.7	
Sext. Corr.		+	-	
I. C.		0.8		
Dip (36 ft)			5.8	
Main Corr			1.7	
Add'l				
SUMS		0.8	7.5	
Corr			-6.7	
Hs		29	52.5	
Ho		29	45.8	
Hc		29	37.7	
a			8.1 A	(T)
Az (interpolate)		089.4		
Zn		089.4		
Advance				

1211. SIGHT REDUCTION BY H.O. 211

Based upon a concept developed by the late Rear Admiral Arthur A. Ageton, while serving as a Lieutenant at the Postgraduate School, U.S. Naval Academy, Annapolis, and published by him in 1931, Dead Reckoning Altitude and Azimuth Tables (H.O. 211) have, in usefulness, stood the test of time. This volume, appropriately and popularly known as "Ageton," includes formulas derived from Napier's rules, and in support of such formulas, tables of log secants and log cosecants for each 0.5' of arc. In a small, compact volume of 49 pages, these tables are useful worldwide, regardless of declination or altitude. A unique feature is that the concept is based upon a DR, rather than an assumed, position.

H.O. 211 advanced the practice of celestial navigation and was widely used until generally replaced by H.O. 214 during World War II. H.O. 211 is briefly described herein because of the economy it offers; a single volume for sight reduction is all that is required. However, the advantage of its economy is perhaps more than offset today by the greater convenience of H.O. 214, H.O. 249, or H.O. 229. For the navigator who wishes, nevertheless, to use H.O. 211, the Ageton method for sight solution or reduction is most adequately described therein.

CHAPTER 13

OTHER CELESTIAL COMPUTATIONS

1301. INTRODUCTION

As important as sight reduction is to celestial navigation, knowledge of such alone will not suffice. Essential supplementary celestial computations are described in this chapter, and include the determination of:

(a) Latitude by meridian sight;
(b) Time of transit, including local apparent noon (LAN);
(c) Latitude by Polaris;
(d) Time of phenomena such as sunrise, moonrise and twilight;
(e) Identification of navigational stars and planets;
(f) Compass error by azimuth of the sun;
(g) Compass error by azimuth of Polaris.

1302. LATITUDE BY MERIDIAN SIGHT

Since the latitude of a position may be determined by finding the distance between the equinoctial and the zenith, one needs to know only the declination and zenith distance (co-altitude) of a body to determine latitude. The procedure involved has been used by mariners for many centuries because of its simplicity. Before the discovery of the Sumner line, and particularly prior to the Harrison chronometer, longitude was most difficult to compute. Accordingly, early mariners seized upon the technique of "latitude or parallel sailing," by which they traveled north or south to the known latitude of their destination, then east or west as appropriate, often using the meridian sight as their only celestial computation. The meridian sight as described herein is applicable to all celestial bodies, although in practice it is primarily used with the sun. As described in Art. 1304, latitude by Polaris, a polar star, is a special case of the meridian sight, and is procedurally a different computation. With this brief introduction, the meridian sight is now considered.

When the altitude of a celestial body is measured as it transits the meridian, we speak of the observation, and the subsequent solution for a line of position, as a "meridian sight." This sight includes observations of bodies on the lower branch of the meridian (lower transit) as well as on the upper branch (upper transit); circumpolar stars may be observed on either branch of the celestial meridian. In practice, however, bodies are seldom observed on the lower branch, and the sun is normally the only body observed. In polar latitudes, when the declination of the sun corresponds in name to the latitude of the observer, the sun may be observed when in lower transit, but generally, meridian sights of the sun are made when it is in upper transit (LAN).

The meridian sight is important for the following reasons:

(a) It provides a celestial LOP without resort to trigonometry;
(b) The intersection of the LOP, obtained at LAN, and advanced morning sun lines, establishes a celestial running fix;
(c) It is practically independent of time;
(d) The knowledge of the approximate position is unnecessary; and
(e) The LOP is a latitude line, and is useful in latitude or parallel sailing.

To observe a body when on the meridian we must first determine the time of local transit. This may be accomplished by one of the three following methods:

(a) MAXIMUM ALTITUDE.—At upper transit the altitude of a celestial body is maximum for a particular 24 hour period. At lower transit the altitude is at a minimum.

(b) AZIMUTH METHOD.—When a celestial body transits the meridian, unless it is in the

observer's zenith (GP corresponding to the observer's position), the azimuth will be either north (000) or south (180).

(c) COMPUTATION METHOD.—Should the approximate longitude be known, it is possible to compute the time of transit. This, the most common method, is described in article 1303.

When making the observation, stand by with a sextant 5 minutes prior to the expected time of transit. Continuously measure the altitude. When the altitude commences to decrease (on an upper branch observation), cease measurement, and record the highest attained value of altitude.

The theory of the meridian sight may be condensed as follows:

(a) It is a special case of the astronomical triangle. Since the local celestial meridian and the hour circle coincide, t equals 0 degrees and we are dealing with an arc rather than a triangle. Geometry, rather than spherical trigonometry, is necessary for solution.

(b) The vertical circle, the hour circle, and the local celestial meridian, coincide.

(c) The azimuth is either 000 or 180, except in the case of a body in the observer's zenith.

(d) The declination of a body is the latitude of the GP.

(e) The zenith distance of a body is the angular distance between the GP of the body and the observer, measured along the meridian.

(f) To find the latitude, it is only necessary to compute declination and zenith distance (co-alt), which may be combined after the derivation of the correct formula.

To derive the correct formula, draw the half of the celestial sphere which extends above the horizon, as viewed by an observer beyond the west point of the horizon (fig. 13-1). The circumference of this half circle represents the observer's celestial meridian which, as we have already noted, coincides with the hour circle and the vertical circle of the body. The zenith-nadir line, the equinoctial, and the polar axis, are all represented as radial lines extending outward from the observer's position at the center of the base line of the diagram. Label the north and south points of the horizon and the zenith. Depending upon the azimuth (north or south), using the observed altitude, measure from the north or south point of the horizon along the vertical circle and locate the position of the celestial body; label the position. Using the declination, locate and label the equinoctial

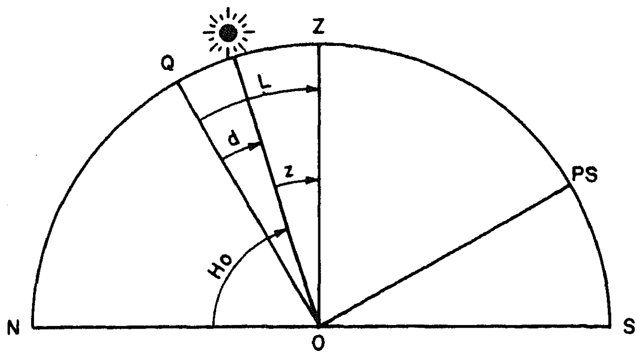


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Figure 13-1.—Sun on meridian.

(Q). If the declination is north, the body will be between N and Q; if the declination is south, the body will be between S and Q. Arc ZQ then equals the latitude of the observer. We can readily see the relationship between declination and zenith distance, and derive formulae for the three possible cases, as follows:

(a) Latitude and declination of different names:

$$L = z - d$$

(b) Latitude and declination of same name with $L < d$:

$$L = d - z$$

(c) Latitude and declination of same name with $L > d$:

$$L = z + d$$

The following special cases are worthy of note:

(a) If $Ho + d = 90°$, then latitude is 0

(b) When latitude is nearly 0, and name of latitude unknown:

(1) If $(Ho + d) > 90$, latitude is of the same name as the direction of the body.

(2) If $(Ho + d) < 90$, latitude is of contrary name to the direction of the body.

(c) Ho plus polar distance equals the latitude at lower transit.

EXAMPLE 1:

Given: DR Lat. 47-26 S, Long. 130-26 W. ZT 11-45-41 on 2 Jan. 1970. Hs of sun (LL) 65-18.3. Zn 000. IC + 2.0. Height of eye 44 feet.

Required: Latitude of the observer.

Solution:

ZT	11-45-41 2 Jan.	
ZD	+9	(130-26/15)
GMT	20-45-41 2 Jan.	
Dec.	S 22-54.1 Code -2	
Code Corr.	-0.2*	
Dec.	22-53.9 S	

	Plus	Minus
IC	2.0	
HE		6.4
Corr.	15.8	
Sum	+17.8	-6.4 = +11.4

*Dec. code -2 indicates that declination changes 0.2' northward per hour and therefore the change to the nearest tenth for 45 min. is also 0.2'.

Hs	65-18.3	90 =	89-60.0
Corr.	+11.4	Ho	65-29.7
Ho	65-29.7	z	24-30.3

(1) Plot sun using Ho and Zn (Draw diagram)
(2) Plot Q using declination and position of sun.
(3) Plot Ps using Q.
(4) ZQ equals latitude. Label angles or arcs in diagram which represent dec, z, and latitude.
(5) Formula is L = z + d

z	24-30.3
d	22-53.9
Lat.	47-24.2-South

1303. COMPUTING ZONE TIME OF LOCAL APPARENT NOON (LAN)

The navigator, using the Nautical Almanac, computes zone time of the sun's upper transit to an accuracy which permits his being on the bridge with sextant in hand just prior to LAN. Of a number of methods available for determining time of LAN, the GHA method is generally used, and for that reason is described herein.

In west longitude, when the sun is on the meridian the GHA equals the longitude. In east longitude, when the sun is on the meridian the GHA is the explement of the longitude. These relationships are illustrated in figure 13-2.

For the purpose of establishing a dead reckoning position to use as an initial estimate, we may assume that the sun will transit our meridian at zone time 1200; we accordingly use the longitude of the 1200 DR position for computing the GHA of the sun at LAN, as LAN will occur between 1130 and 1230, plus or minus the equation of time (unless the observer is keeping a zone time other than standard time for his longitude). Enter the Nautical Almanac with GHA on the correct day, and determine GMT (the reverse of entering with GMT and finding GHA). In conversion of GHA to GMT, first select a value in the GHA column nearest, but less than, the sun's GHA. Record the GMT hours and subtract the GHA at the tabulated hour from the sun's predetermined GHA at LAN. Enter the yellow pages, and in the column headed by Sun — Planets, locate the remainder (minutes and seconds correction to GHA), and record the minutes and seconds. Time — arc conversion tables are also sufficiently accurate for this computation. Combine hours, minutes, and seconds to obtain the GMT of LAN. Apply the zone description, reversing the sign, to obtain zone time of transit.

The time of transit as computed above is the zone time the sun would transit the meridian of

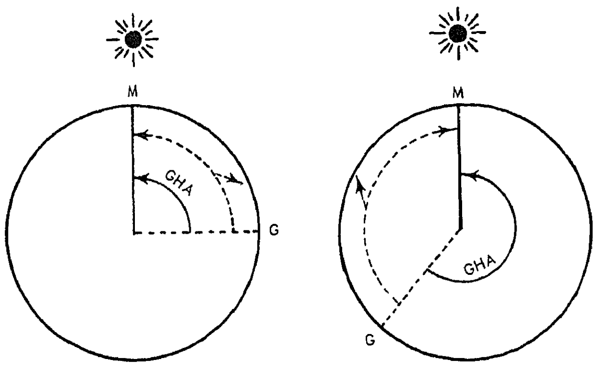

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Figure 13-2.—GHA of sun at LAN.

the 1200 DR position. If this time differs from 1200, and you are the navigator of a moving vessel, then obviously the sun will not transit your meridian exactly at the time computed because of the difference in longitude between your position at 1200 and your position at your first estimated time of LAN. Ship's speeds are relatively slow, and a second estimate is generally not considered necessary. However, if a second estimate is desired, plot the DR corresponding to the time of the first estimate. With dividers, determine the difference in longitude (in minutes of arc) between the 1200 DR and the DR position corresponding to the first estimate of time of LAN. Convert the difference in longitude (in arc) to time, and apply as a correction to the zone time of the first estimate. Keeping in mind that the sun appears to travel from east to west, add the correction if the last plotted DR position is west of the 1200 DR, and subtract the correction if the last plotted DR position is to the eastward.

EXAMPLE 1:

Given: 1200 DR Lat. 36-18 N; Long. 71-19 W. 2 Jan 1970.

Required: ZT of LAN.

Solution:

ZT 1200 Long.	71-19W.	
GHA at LAN	71-19.0	
16 hrs.	58-59.0	
49 min. 20 sec.	12-20.0	
GMT equals	16-49-20	
ZD	+5	(rev)
ZT	11-49-20	

EXAMPLE 2:

Given: 1200 DR Lat. 31-10S; Long.163-10E. 1 Jan 1970

Required: ZT of LAN.

Solution:

ZT 1200 Long.	163-10.0 E	
GHA at LAN	196-50.0 (360-163-10')	
01 hours	194-10.5	
10 min. 38 sec.	2-39.5	
GMT	01-10-38	
ZD	-11	(rev)
ZT	12-10-38	

If the time of LAN is required only to the nearest minute, which is often the case, it can be more quickly determined. One need only to apply a difference in longitude correction to the time of meridian passage of the sun over the Greenwich meridian, as recorded on the daily pages of the Nautical Almanac. See Appendix F. The time of meridian passage, as recorded, is both the Greenwich mean time (GMT), and the local mean time (LMT) of local apparent noon. As mean time, it differs from apparent time (1200) by the equation of time, which is also recorded. As local mean time, it is also the zone time on the central meridian of each time zone. Thus, to find the zone time of local apparent noon on meridians other than the central meridian, the local mean time is corrected to zone time by converting the difference in longitude between the central and the observer's meridians from arc to time, and applying the result to the mean time of meridian passage. The correction is subtracted when east of the central meridian, and added when west.

1304. LATITUDE BY POLARIS

In the diagram used in the derivation of formulae for the solution of meridian sights, we found that arc ZQ equals the latitude of the observer. We can prove geometrically, using the same diagram, that the altitude of the elevated pole equals the declination of the zenith (arc ZQ), and also the latitude.

Although Pn and Ps are not well defined positions which make measurement feasible, a second magnitude star called Polaris (north star) provides a reference for measurement in the northern hemisphere; Polaris has no counterpart

in the southern hemisphere. Polaris may be located in the northern sky between the constellations Ursa Major (big dipper) and Cassiopeia. The two stars in the bowl of the dipper at the greatest distance from the handle, point toward the north star.

Polaris travels in a diurnal circle of small radius around Pn as shown in the diagram in figure 13-3. The polar distance, or radius of the diurnal circle, is "p." The meridian angle is "t." Point 0 is the intersection of the observer's celestial meridian and the celestial horizon. Ho equals the observed altitude. PnH equals p cos t, and is the correction which must be added or subtracted, depending upon whether Polaris is below or above Pn.

It can readily be seen that the value of the correction will depend upon the meridian angle (t), or the position of the observer's meridian with respect to the hour circle of Polaris. Since the SHA is relatively constant, the correction is also a function of the LHA♈. For Polaris, the Nautical Almanac tabulates corrections based upon the LHA♈, the observer's latitude, and the month of the year. In table a_0, the correction is based upon a mean value of SHA and declination of Polaris, and a mean value of 50° north latitude as the position of the observer. Table a_1, entered with LHA♈ and latitude, corrects for the difference between actual latitude and the mean. Table a_2, entered with LHA♈ and the month of the year, corrects for variation in the position of Polaris from its selected mean position. All corrections from these tables contain constants, which make the corrections positive, and which when added together, equal 1 degree. Thus, the correction is added to the Ho, and 1 degree is subtracted to determine latitude.

In summary, latitude may be ascertained in the northern hemisphere by observing the Hs of Polaris, at a known time. From the time, and the DR or estimated longitude, compute the LHA of Aries. Correct Hs to Ho, and using the LHA♈, approximate latitude, and date, determine corrections from Polaris tables a_0, a_1 and a_2. Add total correction to Ho, and subtract 1 degree to obtain latitude.

EXAMPLE 1:

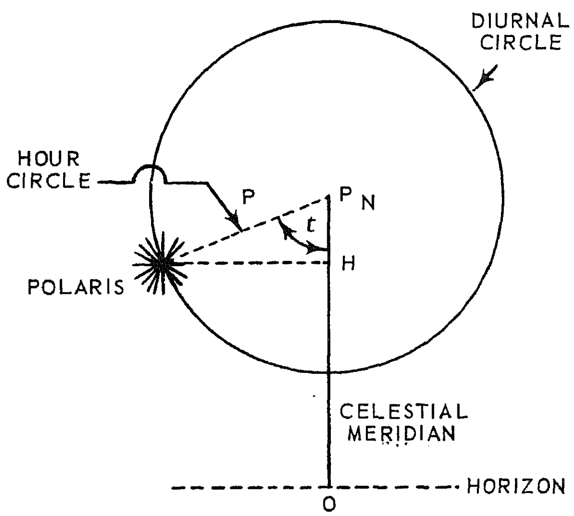
Given: Date 2 Jan. 1970. DR Lat. 67-25.0 N; Long. 116-35.0 W. WT 18-18-45, WE on ZT is 10 seconds fast. Hs 68-21.3. IC + 1.5. HE 42 feet.

Required: Latitude of the observer.

Solution:

			Plus	Minus
WT	18-18-45 2 Jan	IC	1.5	
WE	-10 fast	HE		6.3
ZT	18-18-35	Corr.		0.4
ZD	+8	Sum	+ 1.5	-6.7
GMT♈	02-18-35 3 Jan			+1.5
GHA	132-17.0	Corr.		-5.2
M-S	4-39.5	Hs		68-21.3
GHA ♈	136-56.5	Ho		68-16.1
Long.	116-35.0 W	Table	+	
LHA ♈	20-21.5	a_0	7.6	
Ho	68-16.1	a_1	0.6	
Corr.	-51.1	a_2	0.7	
Lat.	67-25.0 North	Sum	+8.9	
			-60.0	
		Corr.	-51.1	

The reason the Polaris sight cannot be worked by HO 214 is that its declination is about 89 degrees North, and HO 214 does not contain solutions for astronomical triangles based upon any celestial body with such an extreme declination.



190.29
Figure 13-3.—Polaris.

1305. SUNRISE, MOONRISE, AND TWILIGHT

We associate the following phenomena with the apparent motion of the sun and the moon:

SUNRISE—The instant the upper limb of the sun appears on the visible horizon;

MOONRISE—The instant the upper limb of the moon appears on the visible horizon;

SUNSET—The instant the upper limb of the sun disappears beyond the visible horizon;

MOONSET—The instant the upper limb of the moon disappears beyond the visible horizon;

TWILIGHT—The period of semi-darkness occurring just before sunrise (morning twilight), or just after sunset (evening twilight).

The navigator utilizes morning and evening twilight for star observations because during twilight the darkness makes the stars visible, yet permits sufficient light to define the horizon. Both conditions are necessary if an accurate Hs is to be obtained. There are four stages of twilight, based upon the position of the sun with respect to the horizon. They are:

ASTRONOMICAL TWILIGHT.—The sun is 18 degrees below the horizon. Too dark for observations.

NAUTICAL TWILIGHT.—The sun is 12 degrees below the horizon. Favorable for observations. Recorded in Nautical Almanac.

OBSERVATIONAL TWILIGHT.—The sun is 10 degrees below the horizon. Best for observations.

CIVIL TWILIGHT.—The sun is 6 degrees below the horizon. Too light for observations. Also recorded in Nautical Almanac.

In practice, the navigator should be ready to commence his morning observations about 40 minutes before sunrise. For evening observations, he should be ready not later than 15 minutes after sunset.

In the Nautical Almanac the times of sunrise, morning nautical and civil twilight, sunset, and evening nautical and civil twilight, are tabulated against latitude on each daily page for a 3 day period. The time tabulated is Greenwich mean time on the Greenwich meridian but may be regarded as local mean time (LMT) of the phenomena (also the zone time at the central meridian of each time zone). To find the time of sunrise, for example, we turn to the page of the Nautical Almanac for the given date; interpolating for latitude, we find the local mean time of sunrise (zone time on central meridian). If desired, interpolation for latitude can be simplified by the use of a self explanatory table in the back of the Nautical Almanac (see appendix F). Next, we consider the difference in longitude between our meridian and the central meridian. Keeping in mind that 1 degree of arc equals 4 minutes of time, we convert the difference in longitude to time, and apply this correction to the LMT, to find zone time. If the local celestial meridian is to the east of the central meridian of the time zone, subtract the correction; conversely, if the local celestial meridian is to the west, add the correction. Round off answers to the nearest minute.

On a moving ship the problem is slightly more involved. The latitude and longitude chosen for solution should be found by entering the Nautical Almanac with an approximate latitude for sunrise (or sunset, or twilight) and noting the LMT. Plot the DR for the LMT, and using the coordinates of the DR, work the problem in the usual manner, first interpolating for latitude, and secondly applying the correction for longitude. A second estimate is seldom necessary because the required accuracy of 1 minute would not be exceeded unless the vessel traversed more than 15 minutes of longitude between the position of the first estimate and the position reached at the actual time of the phenomenon.

EXAMPLE 1:

Given: Position Lat. 22 N; Long 18 W, 3 Jan. 1970

Required: ZT of sunrise, beginning of morning nautical twilight, sunset, and end of evening civil twilight.

Solution:

	Sunrise	Morning Nautical Twilight	Sunset	Evening Civil Twilight
LMT 30 N	0656	0600	1712	1738
LMT 20 N	0635	0544	1732	1756
diff. for 10	21.0	16.0	20.0	18.0
diff. for 1	2.1	1.6	2.0	1.8
diff. for 2	4.2	3.2	4.0	3.6
LMT 22 N	0639	0547	1728	1752
d Long.*	+12.0	+12.0	+12.0	+12.0
ZT	0651	0559	1740	1804

*(18 - 15) x 4

The Nautical Almanac also tabulates the GMT of moonrise and moonset, which closely approximates values of LMT. The time of moonrise (or moonset) on two successive dates differs a great amount, which makes interpolation for longitude as necessary as interpolation for latitude. To find the precise time of either moonrise or moonset, first find the GMT of moonrise (or moonset) for your latitude; this may necessitate interpolation between given values in the Nautical Almanac, or use of table I. Determine the GMT of moonrise or moonset for the desired date and the preceding date when in east longitude, and for the desired date and the succeeding date, when in west longitude. Compute the time difference between the two GMTs and enter table II with this difference and your longitude. Apply the resulting corection to the GMT of moonrise or moonset on the desired day, generally adding in west or subtracting in east longitude as necessary to arrive at an IMT which in sequence lies between the two previously computed GMTs. Apply a time correction for longitude to the LMT; the result is zone time of moonrise (or moonset).

EXAMPLE 1:

Given: 1 Jan 1970 at Lat. 37–30 N; Long. 63 W.

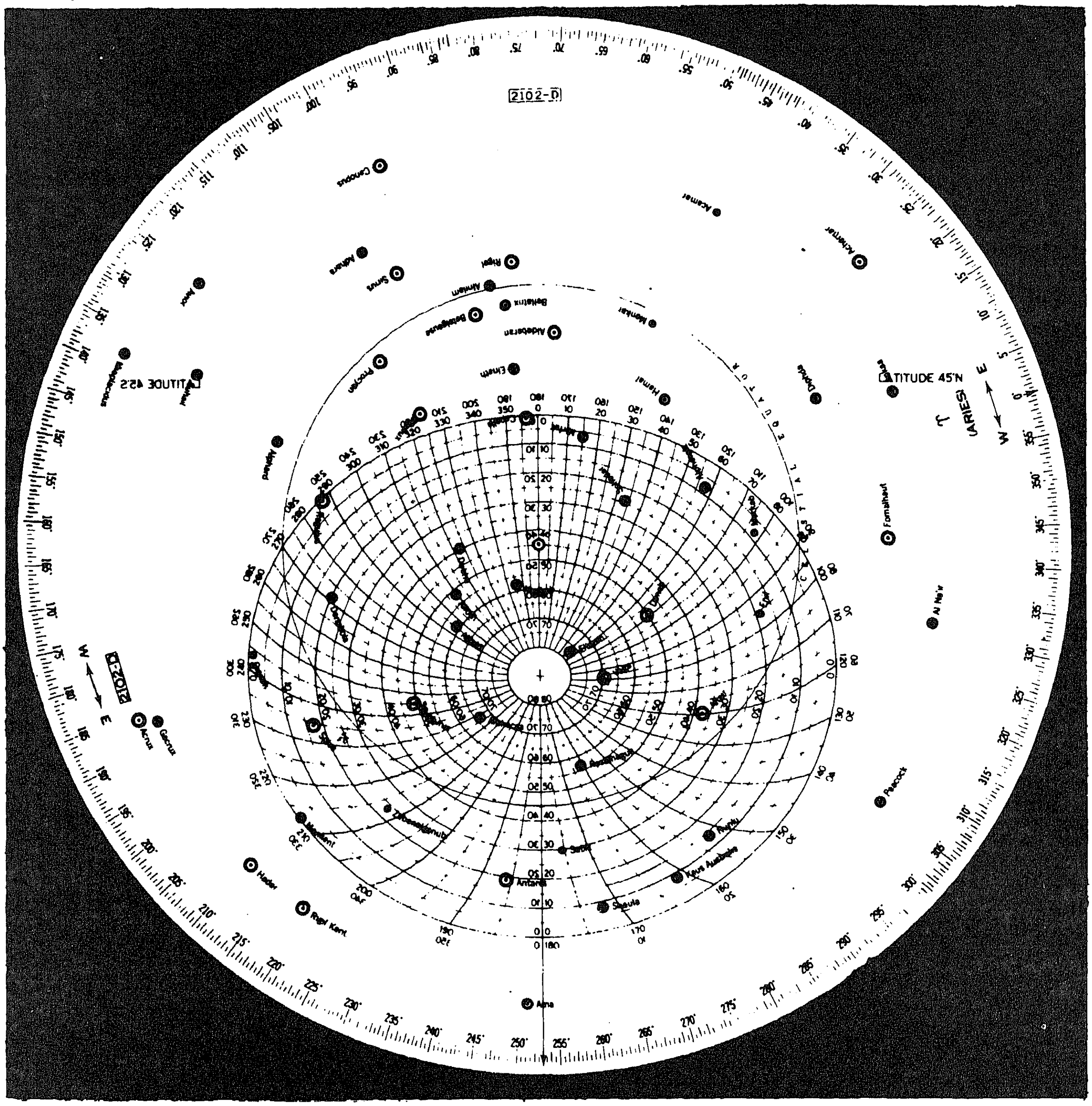
Required: ZT of moonrise.

Solution:

Jan. 1 GMT Lat. 37–30 N	0016	
Jan. 2 GMT Lat. 37–30 N	0119	
Difference	63	min.
Correction (from table II)	+10	
LMT (0016 + 10)	0026	
Corr. for longitude: (63–60) x 4	+12	
ZT of moonrise	0038	

1306. STAR IDENTIFICATION

It is just as necessary for the navigator to correctly identify an observed star as it is for him to identify a navigational landmark in piloting. There are two general systems available,



69.67
Figure 13-4.—Star finder with template.

identification by constellation, and identification by azimuth and altitude. The latter method is most practical, since it permits identification of single stars at twilight when the constellations are not clearly outlined, and of stars visible through breaks in a cloudy sky when constellations are partially or completely obscured.

The navigator's aid to star identification is the Star Identifier (HO 2102D) (fig. 13-4). It consists of a star disc, and a circular transparent template for each 10 degrees of latitude (5, 15, 25, 35, 45, 55, 65, 75, and 85); it also includes a meridian angle template. The star disc is so constructed that the stars normally seen in north latitudes are shown on the north side located so as to indicate their proper Right Ascension (RA) and declination; similarly, those stars normally seen in south latitudes are shown on the south side of the disc. The center of the north side of the disc represents the north celestial pole, and the center of the south side represents the south celestial pole. The edge of the star disc is graduated in degrees (0 to 360) for measurement of both SHA and RA.

To identify stars by their location, using altitude and azimuth, first compute the LHA of Aries for the desired time of observation. Using the side of the star base which corresponds to latitude (north or south), select and mount the transparent template which most nearly corresponds to DR latitude. Since the templates are printed upon both sides, in order to serve for both north and south latitudes, it is necessary to place the template with the side up which corresponds in name (north or south) to your latitude. The template is rotated until a north-south line on the template coincides with the LHA of Aries on the star disc. The printing on the template, which now covers the star base, consists of a network of concentric ellipses and radial lines. The stars which appear within the network are visible at the time of observation (or at least are above the horizon), and have altitudes greater than 10 degrees. The stars outside the network either are below the horizon or will have altitudes less than 10 degrees, and therefore are poor for observation because of inaccuracies in predicted refraction errors. The center of the network represents the observer's zenith. The radial lines represent azimuth, and are 5 degrees apart; at their extremities, the value of the azimuth of any star on that line may be read directly. The concentric ellipses represent circles of equal altitude from 10 to 90 degrees, and are 5 degrees apart; these ellipses are appropriately labeled. Eye interpolation is normally used, and azimuths and altitudes are noted to the nearest degree.

The planets of our solar system do not appear upon the star base because of their constantly changing SHA. To locate or identify planets, the navigator computes the right ascension and declination using the Nautical Almanac. The right ascension of a planet equals the GHA of Aries minus the GHA of the planet. RA may be computed using the GHA's tabulated against a given hour. Once computed and plotted, the navigator will find it unnecessary to replot the planet more often than once every two weeks because the daily change in RA is relatively small.

To plot the planets on the star base, use the red-lined meridian angle template, which can be quickly identified as it contains a rectangular slot. Mount the template according to latitude on the appropriate side of the star base. Set the red pointer, which is adjacent to the slot, so that it indicates the RA of the planet, as read on the periphery of the star base. The planet may then be temporarily plotted through the rectangular slot, using a declination scale on the template adjacent to the slot, to locate its position.

The celestial bodies commonly referred to as morning and evening stars are actually planets, having GHAs which approximate the GHA of the sun. If the GHA of the planet is less than the GHA of the sun, the planet may be called an evening star. If the GHA of the planet is greater than the GHA of the sun, it may be called a morning star.

Consideration in selecting stars for observation are:

(a) Altitude—Between 15 and 70 degrees is preferable. Bodies below 15 degrees have refraction corrections which are predicted with slightly less accuracy. Altitudes above 70 degrees are difficult to measure.

(b) Azimuth—The stars selected should have azimuths which will provide a spread essential to establishing an accurate fix.

(c) Magnitude —Solutions are available for approximately sixty of the brightest stars. Stars of the first magnitude (brightest), are generally used in preference to second magnitude stars because the measurement of the Hs of a bright star is easier than the measurement of the Hs of a dim star.

EXAMPLE 1:

Given: Ho 2102D, North latitude, 1 Jan. 1970.

Required: Plotting of planets.

Solution: RA of a planet equals GHA of Aries minus GHA of planet.

	Venus	Mars	Jupiter	Saturn
GHA of Aries	460-13.8	460-13.8	460-13.8	100-13.8
GHA of Planets	185-22.2	116-17.9	249-40.2	69-27.8
RA of Planets	274-51.6	343-55.9	210-33.6	30-46.0
Dec. of Planets	23-37.9S	7-43.3S	11-08.9S	9-49.3N

The GHA♈ is actually 100-13.8, as indicated above under Saturn; however, it is appropriate to add 360° to the GHA♈ in the above cases for Venus, Mars, and Jupiter, to facilitate subtraction of the GHAs of those bodies. For simplification, the GHAs have all been recorded for 0 hours on 1 Jan., the given date. This is feasible because the hourly change in GHA♈ is practically the same as the hourly change in the GHA of the planets. The difference, or RA, does not differ appreciably during a given day. In fact, the change is so small that once plotted, planets can be used without recomputation and replotting for a fortnight. Planets are plotted using the red-lined, meridian angle template in accordance with their computed right ascensions and declinations. The moon may be plotted, if desired, using its right ascension and declination.

EXAMPLE 2:

Given: ZT 18-20-00 1 Jan. 1970 at Lat. 34-00N, Long. 77-45W, HO 2102D.

Required: List of first magnitude stars and planets visible with altitudes between 15 and 70 degrees.

Solution:

ZT	18-20 1 Jan.
ZD	+5
GMT	23-20 1 Jan.
GHA♈	86-10.5
M/S	5-00.8
GHA	91-11.3
Long.	77-45.0 W
LHA	13-26.3

Star finder set-up:
Disc—north side up.
Template—35 North.
LHA♈ -13-26.3 Planets should already be plotted as required by example (1) above.

Body	Zn	H
Capella	056	40
Betelgeux	093	17
Aldebaran	096	38
Rigel	112	15
Fomalhaut	207	20
Deneb	302	41
Vega	305	18
Mars	220	40
Saturn	126	55

1307. AZIMUTH OF THE SUN

Computation of compass error at sea depends upon the observation of the azimuth of celestial bodies; the sun is most commonly used for this purpose. Upon observation, the observed azimuth, which is abbreviated Zo, is recorded. The time (to the nearest second), and the DR position, are also noted. With DR position and time, the navigator computes Zn. The difference between Zo (compass direction) and Zn (true direction) is compass error (C.E.). It should be appropriately labeled. The fact must be kept in mind that accuracy depends upon the navigator's knowledge of his position and the correct time.

To compute Zn by HO 214, use the Nautical Almanac to solve for t and dec. Using t, dec, and Lat. (all to the nearest tabulated value) enter HO 214, and record the base azimuth angle (Z tab). Next, make an interpolation for difference in t, dec, and Lat.; add algebraically the changes in azimuth angle for the difference between actual and tabulated values. Apply the total interpolative correction to Z tab to obtain Z. Convert Z to Zn. Compare Zn with Zo to determine compass error.

EXAMPLE 1:

Given: Zo 054.6 at Lat. 33-48 S, Long. 161-51 E at WT 11-19-16, 3 Jan. 1970. WE on ZT is 1 min. 6 sec. fast.

Required: Compass error.

Solution:

WT	11-19-16	GHA	178-56.7
WE	1-06 fast	M/S	4-32.5
ZT	11-18-10	Long.	161-51.0E
ZD	-11	LHA	345-20.2
GMT	00-18-10 3 Jan.	t	14-39.8E
		dec	S22-53.2 Code -2
		code corr.	- 0.1
		dec	22-53.1S

				Plus	Minus
t	14-39.8E	t diff + 2.2	t corr.	0.7	
d	22-53.2	d diff + 1.2	d corr.	0.3	
L	33-48.0S	L diff - 2.7	L corr.		0.5
Z tab	126.0		Sum	+1.0	-0.5
Corr.	+0.5		Corr.	+0.5	
Z	S126.5E				
Zn	053.5				
Zo	054.6				
C.E.	1.1 West				

EXAMPLE 2: (By H.O. 229)

	DATE 2 JAN 1970	GB 227.5
**	DR LAT 33°12'N	DR LONG 21°22'W
	ZT	1554 12
	ZD (+W) (-E)	+1
	GMT	1654 12
	GR DATE	2 JAN 1970
	GHA (hrs)	58 59.0
	GHA (m & s)	13 33.0
	TOTAL GHA	72 32.0
	DR LONG (+E) (-W)	21 22.0
**	LHA	51 10.0
	TAB DEC	22 55.0
	d CORR (.2) $\pm$	.2
	TOTAL DEC	22 54.8

(CORR = FACTOR x AZ DIFF)

	EXACT	LOWEST TAB	FACTOR	AZ TAB	AZ INTER'P	AZ DIFF	CORR +	CORR -
DEC	22 54.8	22	$\frac{54.8}{60} = .7$	131.3	132.0	+.7	.64	
DR LAT	33 12.0	33	$\frac{12}{60} = .2$	131.3	131.5	+.2	.04	
LHA	51 10.0	51	$\frac{10}{60} = .8$	131.3	130.5	-.8		.13

TOTAL CORR +.55 or .6

	AZ TAB	131.3
	CORR	+.6
**	AZ	N 131.9 W
		360.0 -131.9
	ZN	228.1
	GB	227.5
	GE	.6 E

** CONVERT AZ TO ZN

NORTH LAT	LHA GREATER THAN 180°..	ZN = AZ
	LHA LESS THAN 180°.......	ZN = 360° - AZ
SOUTH LAT	LHA GREATER THAN 180°...	ZN = 180° - AZ
	LHA LESS THAN 180°	ZN = 180° + AZ

COMPASS BEST ERROR WEST
COMPASS LEAST ERROR EAST

1308. AZIMUTH BY POLARIS

To determine compass error at night in north latitudes, find Zo of Polaris by observation. Compute the LHA of Aries. Enter the Nautical Almanac in the Polaris table entitled "Azimuth" with the arguments (1) LHA of Aries and (2) latitude of the observer. Zn is read directly from this table. Compare Zn and Zo, in the manner described for the sun in the preceding article, and determine compass error.

CHAPTER 14

DUTIES OF THE NAVIGATOR

1401. INTRODUCTION

The duties of the navigator are basically the same regardless of the type or the employment of the vessel; differences arise in methods employed because of available equipment. The duties of the navigator of a Navy vessel stem from, and are found in, Navy Regulations as revised in 1948 and since amended.

1402. DETAILED DUTIES

Extracts from Navy Regulations governing navigation are quoted herewith:

"0929. General Duties

The head of the navigation department of a ship shall be designated the navigator. The navigator normally shall be senior to all watch and division officers. The Chief of Naval Personnel will order an officer as navigator aboard large combatant ships. Aboard other ships the commanding officer shall assign such duties to any qualified officer serving under his command. In addition to those duties prescribed elsewhere in the regulations for the head of department, he shall be responsible, under the commanding officer, for the safe navigation and piloting of the ship. He shall receive all orders relating to navigational duties directly from the commanding officer, and shall make all reports in connection therewith directly to the commanding officer.

0930. Specific Duties

The duties of the navigator shall include:

1. Advising the commanding officer and officer of the deck as to the ship's movements and, if the ship is running into danger, as to a safe course to be steered. To this end he shall:

(a) Maintain an accurate plot of the ship's position by astronomical, visual, electronic or other appropriate means.

(b) Prior to entering pilot waters, study all available sources of information concerning the navigation of the ship therein.

(c) Give careful attention to the course of the ship and depth of water when approaching land or shoals.

(d) Maintain record books of all observations and computations made for the purpose of navigating the ship, with results and dates involved. Such books shall form a part of the ship's official records.

(e) Report in writing to the commanding officer, when under way the ship's position (fig. 14-1) at 0800, 1200, and 2000 each day, and at such other times as the commanding officer may require.

(f) Procure and maintain all hydrographic and navigational charts, sailing directions, light lists, and other publications and devices for navigation as may be required. Maintain records of corrections affecting such charts and publications. Correct navigational charts and publications as directed by the commanding officer and in any event prior to any use for navigational purposes from such records and in accordance with such reliable information as may be supplied to the ship or the navigator is able to obtain.

SHIP'S POSITION
NAVSHIPS-1111 (REV. 5-62)

TO:
COMMANDING OFFICER, USS *Hugh Purvis (DD-709)*

AT (Time of day)	DATE	
1200 R	*15 May, 1965*	
LATITUDE	LONGITUDE	DETERMINED AT
35°01.7′N	*74°38.5′W*	*1145 R*

BY (Indicate by check in box)
☐ CELESTIAL ☒ D. R. ☒ LORAN ☐ RADAR ☐ VISUAL

SET	DRIFT	DISTANCE MADE GOOD SINCE (time) (mi.)
240°	*0.4 Kt.*	*0800 R* *60 Mi.*

DISTANCE TO	MILES	ETA
Brenton Reef Light	*420 Mi.*	*1600 R 16 May*

TRUE HDG.	ERROR	VARIATION
026°	GYRO *0.5E* GYRO °	*8° W*

MAGNETIC COMPASS HEADING (Check one)
☐ STD ☒ STEERING ☐ REMOTE IND ☐ OTHER *035.5°*

DEVIATION	1104 TABLE DEVIATION	DG: (Indicate by check in box)
1.5W°	*1° W*	☐ ON ☒ OFF

REMARKS

RESPECTFULLY SUBMITTED (navigator) *D C Naismith, Ltjg*

CC:

4-58047

112.97
Figure 14-1.—Ships position report.

2. The operation, care, and maintenance of the ship's navigational equipment. To this end he shall:

(a) When the ship is under way and weather permits, determine daily the error of the master gyro and standard magnetic compasses, and report the result to the commanding officer in writing. He shall cause frequent comparisons of the gyro and magnetic compasses to be made and recorded. He shall adjust and compensate the magnetic compasses when necessary, subject to the approval of the commanding officer. He shall prepare tables of deviations, and shall keep correct copies posted at the appropriate compass stations.

(b) Insure that the chronometers are wound daily, that comparisons are made to determine their rates and error, and that the ship's clocks are properly set in accordance with the standard zone time of the locality or in accordance with the orders of the senior officer present.

(c) Insure that the electronic navigational equipment assigned to him is kept in proper adjustment and, if appropriate, that calibration curves or tables are maintained and checked at prescribed intervals.

3. The care and proper operation of the steering gear in general, except the steering engine and steering motors.

4. The preparation and care of the deck log. He shall daily, and more often when necessary, inspect the deck log and the quartermaster's notebook and shall take such corrective action as may be necessary, and within his authority, to insure that they are properly kept.

5. The preparation of such reports and records as are required in connection with his navigational duties, including those pertaining to the compasses, hydrography, oceanography, and meteorology.

6. The relieving of the officer of the deck as authorized or directed by the commanding officer.

0931. Duties When Pilot is on Board

The duties prescribed for a navigator in these regulations shall be performed by him whether or not a pilot is on board.

1403. LEAVING AND ENTERING PORT

The navigator may expect to employ all methods of navigation except celestial, when leaving or entering port. Between a ship's berth and the open sea, the diversified tasks which the navigator must perform may be organized with the use of a check-off list.

The following check-off lists are, with slight modification, appropriate for ships of any type:

(a) Navigation Check-Off List for Getting Under-way—

<u>24 hours before—</u>

1. Make a pre-voyage check of instruments.

2. Check chronometer; determine error and daily rate.
3. Check adjustment of electronic equipment.
4. Read coast pilot or sailing directions which apply to harbor.
5. Determine estimated time of departure.
6. Consult Chief Quartermaster; locate and study desired charts and insure that applicable corrections have been made.
7. Plot courses and distances on harbor and sailing charts. Include route points and times of arrival at route points.
8. Plot danger bearings and danger angles.
9. Determine state of tide upon departure.
10. Determine state of current upon departure.
11. Study light list; plot visibility arcs for lights.
12. Study harbor chart of destination, particularly noting peculiarities which will affect navigation.
13. Check proposed track against dangers to navigation such as wrecks and shoals.
14. Determine total distance and required average speed for the ETA if established.
15. Note available electronic aids.
16. Instruct the navigation detail as to individual piloting tasks while leaving port.
17. Study pilot charts for information relative to the voyage (current and weather).
18. Check markings on the lead line.
19. Determine boundary between inland and international waters.
20. Confer with commanding officer.

4 hours before—

1. If not in operation, start master gyrocompass.

30 minutes before—

1. Station navigation detail.
2. Test fathometer, DRT, electronic equipment, and communication system.
3. Check gyro and repeaters against magnetic compass to determine gyro error.
4. Check vicinity of magnetic compass binnacle to insure that all gear is in place and that no stray magnetic material will influence compass.
5. Record the draft of the ship.
6. Check availability of bearing book, binoculars, stop watch, drafting machine, parallel rulers, navigator's case, charts, maneuvering boards, nautical slide rule (for computations involving time, speed, and distance), sharp pencils, art gum eraser, and thumb tacks. Drafting machine should be oriented to chart.
7. Check readiness of navigation publications (including information concerning local navigational aids).
8. Insure that hand lead is on deck.
9. If anchored, take frequent rounds of bearings during weighing of anchor to detect drift.

Upon getting underway—

1. Keep running plot of ship's position using available landmarks.

2. Advise conning officer of desired courses and speeds and upon ship control.

3. Man chains.

4. Man searchlights at night.

5. CIC commence radar navigation regardless of weather. If fog is encountered, make a decision either to proceed by radar navigation or to anchor.

6. Note dangers to navigation and deficiencies in navigational aids for reporting to Oceanographic Office.

7. Check state of tide and current, and compare with predictions.

Upon leaving channel and passing sea buoy—

1. Lower pit sword (if so equipped); commence operation of log.

2. Secure chains. Continue operation of fathometer.

3. Set latitude and longitude dials, and start DRT.

Before losing sight of land—

1. Obtain departure fix.
2. Secure fathometer, unless desired.
3. Secure piloting instruments.

(b) Navigation Check-Off List for Entering Port -

Before sighting land—

1. Read coast pilots or sailing directions and note comments.

2. Determine estimated time of arrival.

3. Consult Chief Quartermaster; locate and study desired charts and insure their correction (check for late changes in local navigational aids).

4. Determine state of tide upon arrival.

5. Determine expected currents.

6. Start fathometer; record sounding periodically and check approach.

7. Determine expected landmarks and their characteristics.

8. Locate ranges and study buoyage.

9. Plot courses to be used while entering port.

10. Plot danger bearings and danger angles.

11. Study anchorage chart and determine assigned berth.

12. Ascertain pilot regulations and requirements.

13. Check local harbor regulations and/or applicable operation order or plan (garbage, landings, customs, quarantine, forbidden anchorage, cable locations, dredges, survey stations, survey boats, speeds, and special orders).

14. Locate electronic aids to navigation (radio direction finder, radio beacon, coast radar stations, loran stations, etc.).

15. Determine whether or not a degaussing range is available and if a degaussing check is necessary or desirable.

16. Determine boundary between inland and international waters. Log time of crossing; notify captain and conning officer.

17. If at night, determine characteristics of expected lights and check chart data with light list; record the expected time of sighting of major lights. Give a list to the OOD.

18. Check markings on lead line.

19. Exercise watch on both surface search and air search radar to determine distance and shape of coast.

Upon sighting land –

1. Locate position of ship by landmarks as soon as practicable. Correct latitude and longitude dials on DRT.

2. Take soundings continuously.

3. Check compass error on available ranges. Insure proper speed setting on master gyrocompass.

4. Note dangers to navigation and deficiencies in navigational aids for reporting to Oceanographic Office.

5. Station navigation detail. Prepare bearing book.

6. Keep running plot of ship's position using available landmarks.

7. CIC commence radar navigation regardless of weather. If fog is encountered, make a decision either to proceed by radar navigation or to anchor.

8. Check state of tide and current, and compare with predictions.

9. Set watch on lookout sound-powered phone circuit (JL).

10. Man searchlight at night.

Upon entering channel or harbor –

1. Continue above as practicable.

2. House pit sword and sound dome, if required.

3. Determine anchorage bearings; note adjacent ships and other possible dangers.

4. Plot anchorage approach course (against current if possible).

5. Clear sides if mooring alongside ship or dock.

6. Man the chains.

7. Advise conning officer of desired courses and speeds.

8. When approaching berth, advise upon ship control (including the letting go of anchor).

After anchoring or mooring –

1. If anchored, get actual anchorage bearings, plot and enter them in the log. Use sextant and 3-arm protractor if necessary.

2. Determine draft of ship and enter in the log.

3. Advise as to desired scope of anchor chain if anchored. Plot scope of chain (radius of swing).

4. Determine and log the actual depth of water and type of bottom.

5. Check distances to adjacent ships and landmarks. Compare with radar ranges.

6. If in unsurveyed anchorage, determine soundings and character of bottom in circular area having a radius equal to 1 1/2 times the swinging circle, with the anchor at center.

7. Check expected currents and if anchored, put over drift lead.

8. Locate landings if anchored. Notify OOD of boat compass course to and from landings.

9. Recheck ship's position if anchored as soon as ship is steadied against current. Advise captain whether anchor is holding.

10. If anchored, station the anchor watch. Take bearings to detect dragging.

1404. COASTAL PILOTING

Coastal piloting makes use of the same principles as harbor piloting. Although the period practiced may be so extended as to work a physical hardship on the navigator, safety requires that the navigator identify all aids and be on deck to

witness all course changes. This requirement is necessary because of the proximity of danger. The navigator should constantly be governed by the thought "a mariner's first consideration is the safety of his vessel."

1405. NAVIGATION AT SEA

The navigator's sea routine is as follows:

Morning twilight—Observe stars and compute star fix.

Sunrise (or after)—Compute compass error.

0800—Make position report.

Forenoon—Obtain morning sun line. Compute time of LAN.

LAN—Observe sun on meridian and compute latitude. Advance morning sun line and obtain running fix.

1200—Make position report.

Afternoon—Obtain afternoon sun line. Advance latitude line obtained at LAN and plot afternoon running fix. Compute time of sunset and prepare list of evening stars.

Evening twilight—Observe stars and compute star fix.

2000—Make position report.

Night—Compute time of sunrise and prepare a list of morning stars. Plot DR for night, making allowance for expected changes in course, speed, and zone time. Observe Polaris, if a compass error check is desired, and if in northern latitudes. Provide navigational data for captain's night orders.

1406. PREPARATION OF THE POSITION REPORT

The following condensed instructions should enable the navigator to properly fill in and submit written reports of the ship's position:

(a) OBJECTIVE—To inform the commanding officer and flag officer (if embarked) of the ship's position, together with recommendations that may be appropriate.

(b) INSTRUCTIONS FOR PREPARATION—

(1) Heading: Record name of ship, time and date on first and second blank lines. Time will be 0800, 1200, 2000, or such time as the CO desires.

(2) Position: In line three, record latitude and longitude (for 0800, 1200 or 2000) and time of observations upon which position is based. In line four, indicate type of fix (celestial, D.R., loran, radar or visual). Label latitude and longitude. Label time, indicating zone.

(3) Set and drift: Compute and record on line five as follows: The set is the direction of the fix from the DR position of the same time. The drift in knots is the distance in nautical miles between the fix and the DR position divided by the number of hours between the times of the last two fixes. Drift is speed.

(4) Distance: Also on line five, record distance made good since last report, giving the time first and the distance second. After "Distance to," on line six, write in either the name of the destination, or a designated route point, and record the distance in nautical miles. Note the time and date of ETA.

(5) Compass data: Record true heading and gyro error. Two blanks are available for gyro error since heavy ships may carry two gyrocompasses. Record variation. Check "STD," "Steering," or "remote IND" to identify the magnetic compass. Record the compass heading which differs from true course by compass error. Record actual and table deviation. Remember that the algebraic sum of variation and deviation is compass error. Use degrees and tenths of degrees and label all values except heading as "east" or "west." Check degaussing as either "on" or "off."

(6) Remarks: Make recommendations as to changes in course, speed, and zone time. Inform the captain of navigational aids expected to be sighted, using back of report if necessary. This report ordinarily should be sufficiently complete to provide the captain with all information necessary to write the night orders.

Example: "Recommend c/c to 050 (T) at 2200 with Frying Pan Shoals Lt. Ship abeam to port, distance 4 miles. Sight Diamond Shoals Lt. Ship bearing 045(T) at 0623, distance 16 miles. Characteristics—GpFl W ev 26 sec (3 flashes). At 0700 with Diamond Shoals Lt. Ship abeam to port, distance 7 miles, recommend c/c to 000(T); c/s to 17 kts." If you are unable to obtain necessary data, leave appropriate spaces blank and explain under remarks.

(7) Signature: Sign name and indicate rank.

(8) Addressees: The report always goes to the commanding officer. If any flag officers are embarked, insert their titles under "commanding officer" and prepare copies for them. Retain one copy for your file.

1407. LIFE BOAT NAVIGATION

Should an emergency arise which restricts the navigator's tools to the equipage of his life boat, then he must modify the procedures described in this compendium to fit the situation. Success in life boat navigation may be a measure of the navigator's foresight and resourcefulness.

The forehanded navigator accepts the possibility of shipwreck and prepares one or more navigation kits to supplement the equipage regularly carried by his ship's life boats. The navigation kit should contain the following:

(a) An OILCLOTH CHART of sufficient area to show the ship's position if abandoned.

(b) SEXTANT. An inexpensive instrument may be substituted for the commonly used endless tangent screw sextant since accuracy is not paramount.

(c) COMPASS. A pocket compass is small and inexpensive and may be the only direction reference if the boat compass carried by your life boat becomes lost or damaged.

(d) ALMANAC. The convenience of using the Nautical Almanac and especially the star diagrams which it contains makes this publication worth its space. An oilcloth copy of the star diagrams, such as may be found in the Air Almanac, should be carried if available.

(e) TABLES. The appropriate volume of H.O. 214, or other navigational table.

(f) PLOTTING EQUIPMENT. A Hoey position plotter, pencils, and erasers are essential. The Hoey plotter is especially important since it provides both a protractor and a straight-edge; it is also a crude substitute for a sextant.

(g) NOTEBOOK. This book should contain space for computations and a section devoted to a compilation of useful formulae; if an Almanac is not available within the navigation kit, then extracts may be recorded in the notebook. In addition to this notebook, position plotting sheets or other suitable plotting paper should be included in the kit. If a chart is not available, then the coordinates of several ports should be recorded in the notebook. It is advisable to include data on prevailing winds and currents.

(h) AMERICAN PRACTICAL NAVIGATOR. This volume can be most valuable. It contains much information on weather and currents, tables for sight reduction, a long-term almanac, traverse tables for mathematical dead reckoning, and tabulated coordinates of world ports. If including the entire volume is not desirable because of size, appropriate information should be extracted and retained.

(i) PORTABLE RADIO. To obtain time signals, a portable radio is useful.

(j) SLIDE RULE. A slide rule with a sine scale can be used in sight reduction.

(k) DRAMAMINE. Since a sea sickness preventative may act in the interest of the navigator's personal efficiency, dramamine tablets have a place in the kit.

When the ship is abandoned the navigator should accomplish the following if possible:

(a) Wind the watch and determine the watch error.

(b) Record (or at least remember) the date.

(c) Record the ship's position. A recent fix or a fairly accurate EP is most essential when abandoning ship and also on the occasion of "man overboard."

(d) Record magnetic bearing of nearest land and the magnetic variation.

(e) Insure presence of the navigation kit.

After the ship is abandoned, make an estimate of the situation. Consider every possibility, then (1) mentally list and compare the advantages and disadvantages of each, (2) compare the possible outcomes of each, and (3) formulate an alternate plan to be followed in the event of failure of each major plan. Make a decision as to your course of action. Generally, the choice will be between remaining in the immediate vicinity and proceeding toward some land or haven. Record the decision in your notebook and start a log. Make a comparison of watches, if more than one is present, as insurance of correct time. Check speed by the chip log method (art. 303) and insure that the compass is free from magnetic influence other than the earth's. Establish your daily routine.

Start a dead reckoning track upon your chart, or commence dead reckoning mathematically, in order to carry out your course of action. If dead reckoning is to be accomplished by mathematical rather than graphic means, the navigator may use the traverse tables which provide a simplified method of solving any right triangle; if desired, extracts from these tables (which appear as Table 3 in the American Practical Navigator) may be recorded in the notebook during the preparation of the navigation kit. Check the accuracy of your compass in the northern hemisphere by observing Polaris, assuming that its Zn is 000. Magnetic variation

should constitute the entire compass error in a life boat. In either north or south latitude, any body will reach its highest altitude when in upper transit (azimuth 000 or 180) and will thereby provide a compass check. At night, not only Polaris, but any star near the prime vertical, if visible, can be used for a direction reference.

To measure the altitude of celestial bodies in the absence of a sextant, attach a weight to the end of the drafting arm of the Hoey plotter. Sight along the straightedge of the protractor (diameter) and allow the weighted drafting arm to seek alignment with the direction of the force of gravity. Record the angle on the protractor scale between the 0 mark opposite the body and the center of the drafting arm. This angle is the altitude. To correct a measured altitude when the Nautical Almanac is not available, the following information should be tabulated in the notebook:

Refraction Correction for Altitude				Semidiameter
Alt.	Corr.	Alt.	Corr.	
5–6°	-9'	13–15°	-4'	Sun (upper limb) – 16'
7°	-8'	16–21°	-3'	Sun (lower limb) +16'
8°	-7'	22–33°	-2'	
9–10°	-6'	34–63°	-1'	
11–12°	-5'	64–90°	-0	

To find the approximate declination of the sun, draw a circle with horizontal and vertical diameters. Label the points of termination of the diameters as follows, commencing at the top and moving clockwise: June 22, Sept. 23, Dec. 22, and Mar. 21. Locate a given date on the circle with respect to the equinoxes and solstices using proportional parts of any quadrant. Divide the upper vertical radius into 23.45 equal parts to indicate north declination, and divide the lower vertical radius into 23.45 equal parts to indicate south declination. Draw a line from any given date on the circle perpendicular to the vertical to determine the declination on the given date.

The LATITUDE may be determined as follows:

(a) In the northern hemisphere, by an observation of Polaris.

(b) By a meridian sight of any body.

(c) Note bodies at or near the zenith. The latitude of an observer equals the declination of a body in his zenith.

(d) If the Nautical Almanac is available and the date is known, note the duration of daylight which is a function of latitude.

The LONGITUDE may be found by observing and noting time of meridian transit.

A LINE OF POSITION may be obtained by noting the time of sunrise or sunset, or the instant any celestial body coincides with the visual horizon.

To obtain a line of position by a horizon sight, no sextant is needed. For a horizon sight in the case of the sun or the moon, either limb may be used. The Hs, which is 0°, is corrected for height of eye (dip), refraction and semidiameter. Sight reduction may be accomplished using H.O. 211 or H.O. 229; H.O. 214, however, is not applicable for sights of less than 5° altitude. It should be noted that when both H_0 and H_c are negative, the intercept is "away" if H_0 is the greater, and conversely, the intercept is "toward" if H_c is the greater.

Horizon sights may be reduced through the use of a slide rule with a sine scale. The following formula applies:

$$\sin H_c = \sin L \sin d \pm \cos L \cos d \cos t$$

In the formula above, if $t < 90°$, and latitude and declination are of the same name, the sign is positive; when latitude and declination are of contrary name and $t < 90°$, the lesser quantity is subtracted from the greater. If $t > 90°$, and latitude and declination are of the same name, the lesser quantity is also subtracted from the greater; if latitude and declination are of contrary name and $t > 90°$, the sign is positive. If the sine of H is negative, H_c is negative. Azimuth angle may be found using the formula:

$$\sin Z = \frac{\cos d \sin t}{\cos H_c}$$

Since the cosine of H_c in a low altitude sight approaches one, or unity, division by cos H_c is generally unnecessary.

In horizon sights, the azimuth should also be checked to determine compass error. To compute Zn, one needs to know only the declination. With north declination, the body will rise and set at points on the horizon north of the prime vertical an angular distance equal to the declination. With south declination, the body will rise and set at points on the horizon south of the prime vertical an angular distance equal to the declination.

Should the watch or other timepiece stop, it can be reset by an observation of the stars and a reference to a star chart. The navigator remembers that sidereal time and solar time are equal at the autumnal equinox; at the vernal equinox, sidereal time is 12 hours fast on solar time. For any date in between the equinoxes, we can compute the difference between sidereal time and solar time as we know that sidereal time gains 3 minutes and 56 seconds daily. If we see on the star chart that the RA of Diphda (for example) is 10°-30' or 42 minutes of time, then when Diphda is in upper transit, the local sidereal time is 0042 because Aries transits our local meridian (LST 0000) earlier than any given star by an amount of time equal to the RA. From sidereal time we subtract the difference between it and solar time (which depends upon date as explained above) and we arrive at solar mean time.

It is generally best to practice latitude or parallel sailing, since latitude computations are apt to be more accurate than longitude computations. In parallel sailing, the navigator sails in a general direction of either north or south until he reaches the latitude of his destination. Then he changes course to east or west and makes adjustments as necessary enroute in order that his track will adhere to the parallel of latitude of the destination. The navigator should try to compute his daily advance, which among other uses, acts as a check against the longitude when traveling east or west, and as a check against the latitude when traveling north or south.

When landfall is finally made, identify available landmarks and approach with caution until able to select a safe landing site.

APPENDICES

Appendix A	Nautical Chart Symbols and Abbreviations (Chart No. 1)
Appendix B	Useful Physical Laws and Trigonometric Functions
Appendix C	Extracts from Tide Tables, East Coast, 1970
Appendix D	Extracts from Tidal Current Tables, East Coast, 1970
Appendix E	Luminous Range Diagram/Distance of Visibility of Objects at Sea
Appendix F	Extracts from The Nautical Almanac, 1970
Appendix G	Extracts from Tables of Computed Altitude and Azimuth, H.O. 214, Vol. IV
Appendix H	Mechanics of "Error Finding" in Sight Reduction by HO 214
Appendix I	Extracts from Sight Reduction Tables for Air Navigation, HO 249, Volume 1
Appendix J	Extracts from Sight Reduction Tables for Air Navigation, HO 229, Volume 3
Appendix K	U.S. Navy Navigation Workbook, Format and Instructions, including Forms
Appendix L	Additional Celestial Work Forms

Appendix A

GENERAL REMARKS

Chart No. 1 contains the standard symbols and abbreviations which have been approved for use on nautical charts published by the United States of America.

Symbols and abbreviations shown on Chart No. 1 apply to the regular nautical charts and may differ from those shown on certain reproductions and special charts. Symbols and abbreviations on certain reproductions and on foreign charts may be interpreted by reference to the Symbol Sheet or Chart No. 1 of the originating country.

Terms, symbols and abbreviations are numbered in accordance with a standard form approved by a Resolution of the Sixth International Hydrographic Conference, 1952.

Vertical figures indicate those items where the symbol and abbreviation are in accordance with the Resolutions of the International Hydrographic Conferences.

Slanting figures indicate no International Hydrographic Bureau symbol adopted.

Slanting figures underscored indicate U.S.A. and I.H.B. symbols do not agree.

Slanting figures asterisked indicate no U.S.A. symbol adopted.

An up-to-date compilation of symbols and abbreviations approved by resolutions of the International Hydrographic Conference is not currently available. Use of I.H.B. approved symbols and abbreviations by member nations is not mandatory.

Slanting letters in parentheses indicate that the items are in addition to those shown on the approved standard form.

Colors are optional for characterizing various features and areas on the charts.

Lettering styles and capitalization as used on Chart No. 1 are not always rigidly adhered to on the charts.

Longitudes are referred to the Meridian of Greenwich.

Scales are computed on the middle latitude of each chart, or on the middle latitude of a series of charts.

Buildings - A conspicuous feature on a building may be shown by a landmark symbol with descriptive note ('See I-n & L-63'). Prominent buildings that are of assistance to the mariner are crosshatched (See I-3a,5,47 & 66).

Shoreline is the line of Mean High Water, except in marsh or mangrove areas, where the outer edge of vegetation (berm line) is used. A heavy line (A-9) is used to represent a firm shoreline. A light line (A-7) represents a berm line.

Heights of land and conspicuous objects are given in feet above Mean High Water, unless otherwise stated in the title of the chart.

Depth Contours and Soundings may be shown in meters on charts of foreign waters.

Visibility of a light is in nautical miles for an observer's eye 15 feet above water level.

Buoys and Beacons - On entering a channel from seaward, buoys on starboard side are red with even numbers, on port side black with odd numbers. Lights on buoys on starboard side of channel are red or white, on port side white or green. Mid-channel buoys have black-and-white vertical stripes. Junction or obstruction buoys, which may be passed on either side, have red-and-black horizontal bands. This system does not always apply to foreign waters. The dot of the buoy symbol, the small circle of the light vessel and mooring buoy symbols, and the center of the beacon symbol indicate their positions.

Improved channels are shown by limiting dashed lines, the depth, month, and the year of latest examination being placed adjacent to the channel, except when tabulated.

U. S. Coast Pilots, Sailing Directions, Light Lists, Radio Aids, and related publications furnish information required by the navigator that cannot be shown conveniently on the nautical chart.

U. S. Nautical Chart Catalogs and Indexes list nautical charts, auxiliary maps, and related publications, and include general information (marginal notes, etc.) relative to the charts.

A glossary of foreign terms and abbreviations is generally given on the charts on which they are used, as well as in the Sailing Directions.

Charts already on issue will be brought into conformity as soon as opportunity affords.

All changes since the September 1963 edition of this publication are indicated by the symbol † in the margin immediately adjacent to the item affected.

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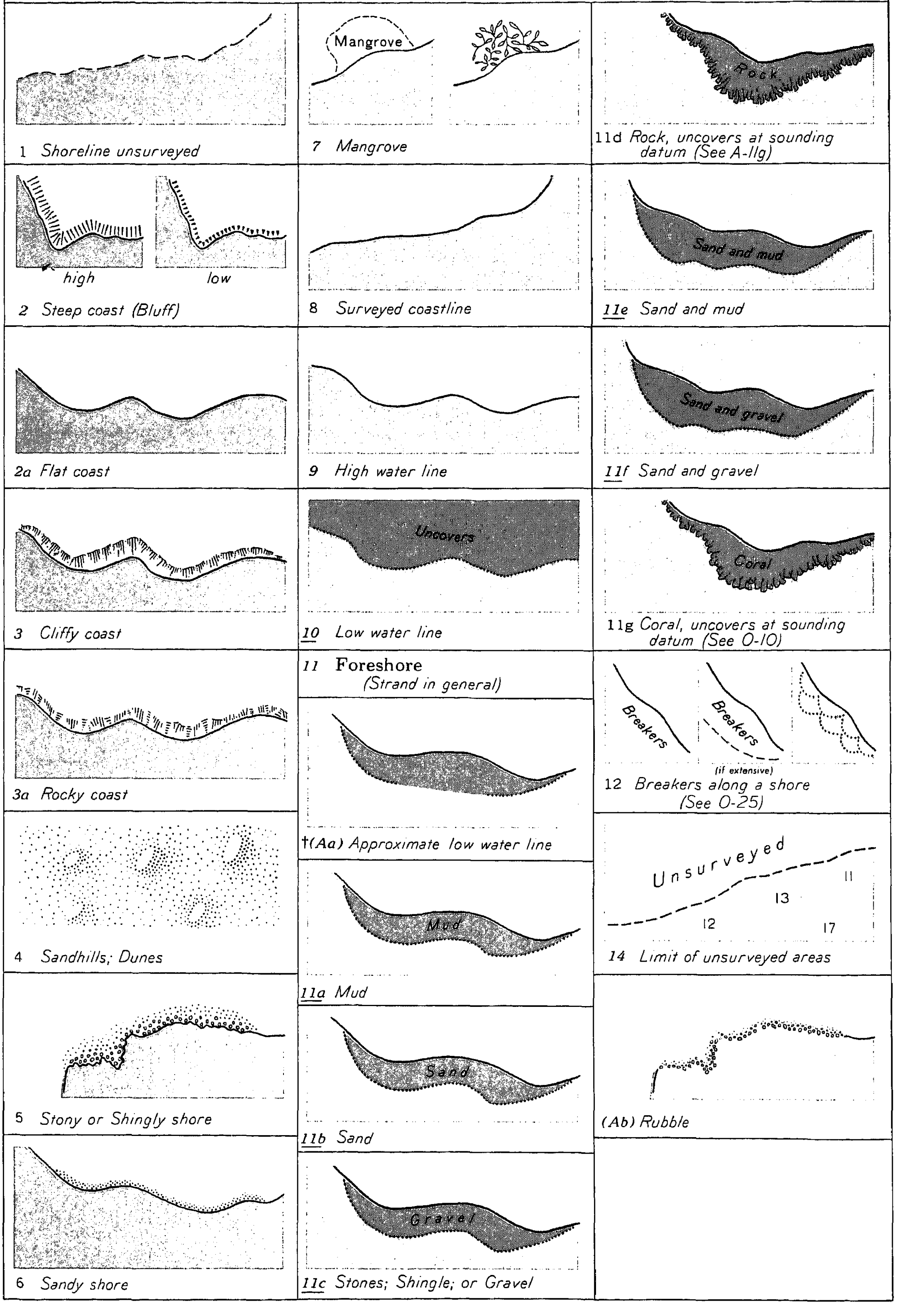
U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
COAST AND GEODETIC SURVEY

A. The Coastline (Nature of the Coast) (see General Remarks)

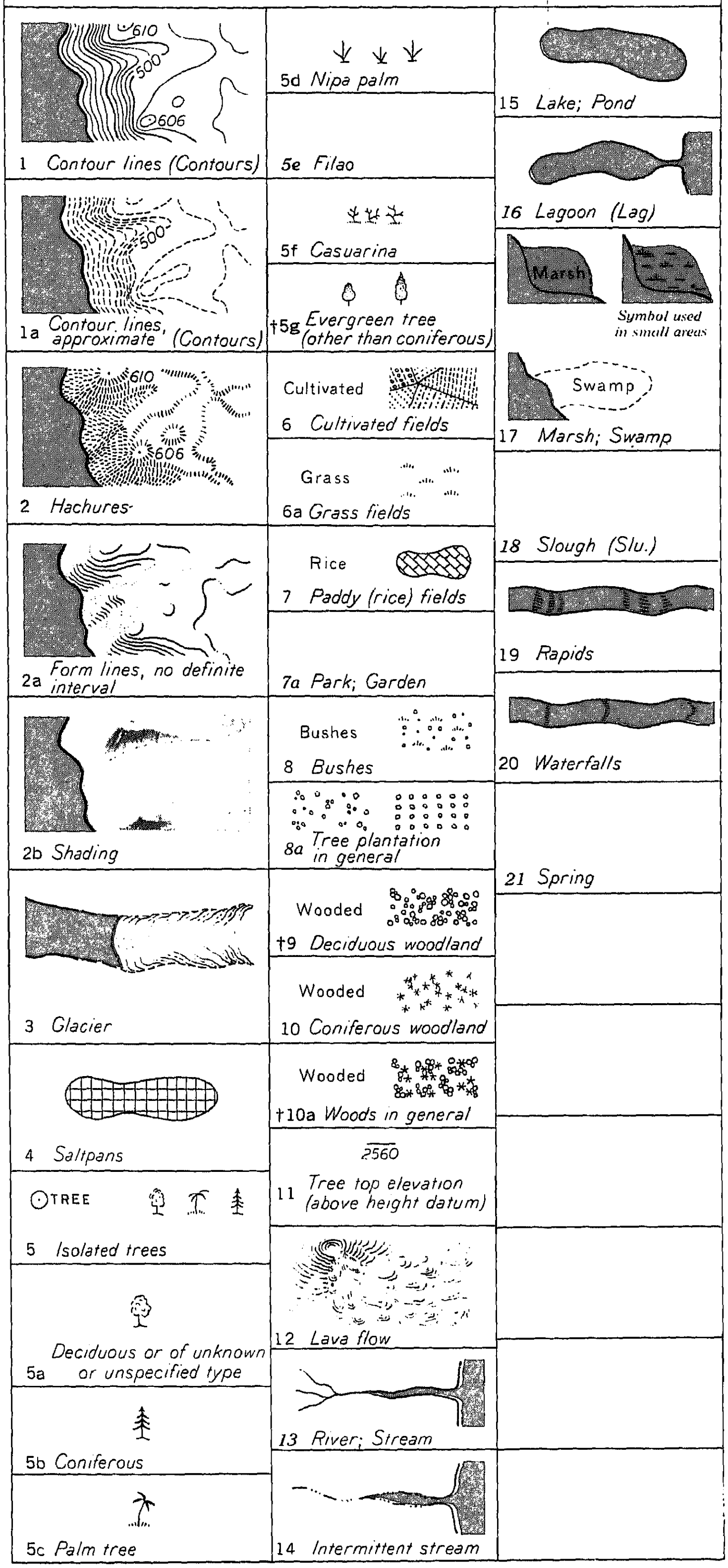


1 *Shoreline unsurveyed*	7 *Mangrove*	11d *Rock, uncovers at sounding datum (See A-11g)*
2 *Steep coast (Bluff)*	8 *Surveyed coastline*	11e *Sand and mud*
2a *Flat coast*	9 *High water line*	11f *Sand and gravel*
3 *Cliffy coast*	10 *Low water line*	11g *Coral, uncovers at sounding datum (See O-10)*
3a *Rocky coast*	11 **Foreshore** *(Strand in general)*	12 *Breakers along a shore (See O-25)*
4 *Sandhills; Dunes*	†(Aa) *Approximate low water line*	14 *Limit of unsurveyed areas*
5 *Stony or Shingly shore*	11a *Mud*	(Ab) *Rubble*
6 *Sandy shore*	11b *Sand*	
	11c *Stones; Shingle; or Gravel*	

B. Coast Features

1	G	*Gulf*
2	B	*Bay*
(Ba)	B	*Bayou*
3	Fd	*Fjord*
4	L	*Loch; Lough; Lake*
5	Cr	*Creek*
5a	C	*Cove*
6	In	*Inlet*
7	Str	*Strait*
8	Sd	*Sound*
9	Pass Thoro	*Passage; Pass* *Thorofare*
10	Chan	*Channel*
10a		*Narrows*
11	Entr	*Entrance*
12	Est	*Estuary*
12a		*Delta*
13	Mth	*Mouth*
14	Rd	*Road; Roadstead*
15	Anch	*Anchorage*
16	Hbr	*Harbor*
16a	Hn	*Haven*
17	P	*Port*
(Bb)	P	*Pond*
18	I	*Island*
19	It	*Islet*
20	Arch	*Archipelago*
21	Pen	*Peninsula*
22	C	*Cape*
23	Prom	*Promontory*
24	Hd	*Head; Headland*
25	Pt	*Point*
26	Mt	*Mountain; Mount*
27	Rge	*Range*
27a		*Valley*
28		*Summit*
29	Pk	*Peak*
30	Vol	*Volcano*
31		*Hill*
32	Bld	*Boulder*
33	Ldg	*Landing*
34		*Table-land (Plateau)*
35	Rk	*Rock*
36		*Isolated rock*
(Bc)	Str	*Stream*
(Bd)	R	*River*
(Be)	Slu	*Slough*
(Bf)	Lag	*Lagoon*
(Bg)	Apprs	*Approaches*
(Bh)	Rky	*Rocky*

C. The Land (Natural Features)



D. Control Points

1	△		*Triangulation point (station)*
†1a			*Astronomic Station*
2	⊙		*Fixed point (landmark) (See L-63)*
†(Da)	∘		*Fixed point (landmark, position approx.)*
3	· 256		*Summit of height (Peak) (when not a landmark)*
(Db)	◎256		*Peak, accentuated by contours*
(Dc)	256		*Peak, accentuated by hachures*
(Dd)			*Peak, elevation not determined*
(De)	⊙ 256		*Peak, when a landmark*
4	⊕	Obs Spot	*Observation spot*
*5		BM	*Bench mark*
†6	View X		*View point*
7			*Datum point for grid of a plan*
8			*Graphical triangulation point*
9		Astro	*Astronomical*
10		Tri	*Triangulation*
(Df)		C of E	*Corps of Engineers*
12			*Great trigonometrical survey station*
13			*Traverse station*
14		Bdy Mon	*Boundary monument*
(Dg)	◇		*International boundary monument*

E. Units

1	hr	*Hour*	†14a		*Greenwich*
2	m; min	*Minute (of time)*	15	pub	*Publication*
3	sec	*Second (of time)*	16	Ed	*Edition*
4	m	*Meter*	17	corr	*Correction*
4a	dm	*Decimeter*	18	alt	*Altitude*
4b	cm	*Centimeter*	19	ht; elev	*Height; Elevation*
4c	mm	*Millimeter*	20	°	*Degree*
4d	m^2	*Square meter*	21	′	*Minute (of arc)*
4e	m^3	*Cubic meter*	22	″	*Second (of arc)*
5	km	*Kilometer*	23	No	*Number*
6	in	*Inch*	(Ea)	St M	*Statute mile*
7	ft	*Foot*	(Eb)	msec	*Microsecond*
8	yd	*Yard*	†(Ec)	Hz	*Hertz (cps)*
9	fm	*Fathom*	†(Ed)	kHz	*Kilohertz (kc)*
10	cbl	*Cable length*	†(Ee)	MHz	*Megahertz (Mc)*
11	M	*Nautical mile*	†(Ef)	cps	*Cycles/second(Hz)*
12	kn	*Knot*	†(Eg)	kc	*Kilocycle (kHz)*
12a	t	*Ton*	†(Eh)	Mc	*Megacycle (MHz)*
12b	cd	*Candela (new candle)*			
13	lat	*Latitude*			
14	long	*Longitude*			

F. Adjectives, Adverbs and other abbreviations

1	gt	*Great*
2	lit	*Little*
3	lrg	*Large*
4	sml	*Small*
5		*Outer*
6		*Inner*
7	mid	*Middle*
8		*Old*
9	anc	*Ancient*
10		*New*
11	St	*Saint*
12	conspic	*Conspicuous*
13		*Remarkable*
14	D . Destr	*Destroyed*
15		*Projected*
16	dist	*Distant*
17	abt	*About*
18		*See chart*
18a		*See plan*
19		*Lighted; Luminous*
20	sub	*Submarine*
21		*Eventual*
22	AERO	*Aeronautical*
23		*Higher*
†23a		*Lower*
24	exper	*Experimental*
25	discontd	*Discontinued*
26	prohib	*Prohibited*
27	explos	*Explosive*
28	estab	*Established*
29	elec	*Electric*
30	priv	*Private, Privately*
31	prom	*Prominent*
32	std	*Standard*
33	subm	*Submerged*
34	approx	*Approximate*
†35		*Maritime*
†36	maintd	*Maintained*
†37	aband	*Abandoned*
†38	temp	*Temporary*
†39	occas	*Occasional*
†40	extr	*Extreme*
†41		*Navigable*
†42	N M	*Notice to Mariners*
†(Fa)	L N M	*Local Notice to Mariners*
†43		*Sailing Directions*
†44		*List of Lights*
(Fb)	unverd	*Unverified*
(Fc)	AUTH	*Authorized*
(Fd)	CL	*Clearance*
(Fe)	cor	*Corner*
(Ff)	concr	*Concrete*
(Fg)	fl	*Flood*
(Fh)	mod	*Moderate*
(Fi)	bet	*Between*
(Fj)	1st	*First*
(Fk)	2nd	*Second*
(Fl)	3rd	*Third*
(Fm)	4th	*Fourth*

G. Ports and Harbors

No.	Symbol	Abbreviation	Meaning
1		Anch	*Anchorage (large vessels)*
†2		Anch	*Anchorage (small vessels)*
3		Hbr	*Harbor*
4		Hn	*Haven*
5		P	*Port*
6		Bkw	*Breakwater*
6a			*Dike*
7			*Mole*
8			*Jetty (partly below MHW)*
8a			*Submerged jetty*
(Ga)			*Jetty (small scale)*
9		Pier	*Pier*
10			*Spit*
11			*Groin (partly below MHW)*
12	ANCHORAGE PROHIBITED	ANCH PROHIB	*Anchorage prohibited (See P-25)*
†12a			*Anchorage reserved*
†12b	QUARANTINE ANCHORAGE	QUAR ANCH	*Quarantine anchorage*
13	Spoil Area		*Spoil ground*
(Gb)	Dumping Ground		*Dumping ground*
(Gc)	80 83 Disposal Area 85 Depths from survey of JUNE 1968 90 98		*Disposal area*
14		Fsh stks	*Fisheries; Fishing stakes*
14a			*Fish trap; Fish weirs (actual shape charted)*
14b			*Duck blind*
15			*Tunny nets (See G-14a)*
15a	Oys	Oys	*Oyster bed*
16		Ldg	*Landing place*
17			*Watering place*
18		Whf	*Wharf*
19			*Quay*
20			*Berth*
20a	14		*Anchoring berth*
20b	3		*Berth number*
21		Dol	*Dolphin*
22			*Bollard*
23			*Mooring ring*
24			*Crane*
25			*Landing stage*
25a			*Landing stairs*
26		Quar	*Quarantine*
27			*Lazaret*
*28		Harbor Master	*Harbor master's office*
29		Cus Ho	*Customhouse*
30			*Fishing harbor*
31			*Winter harbor*
32			*Refuge harbor*
33		B Hbr	*Boat harbor*
34			*Stranding harbor (uncovers at LW)*
35			*Dock*
36			*Dry dock (actual shape on large-scale charts)*
37			*Floating dock (actual shape on large-scale charts)*
38			*Gridiron; Careening grid*
39			*Patent slip; Slipway; Marine railway*
39a		Ramp	*Ramp*
†40	Lock		*Lock (point upstream) (See H-13)*
41			*Wet dock*
42			*Shipyard*
43			*Lumber yard*
44		Health Office	*Health officer's office*
45		Hk	*Hulk (actual shape on lrg scale charts) (See O-11)*
46	PROHIBITED AREA		*Prohibited area*
†46a	10		*Calling-in point for vessel traffic control*
47			*Anchorage for seaplanes*
48			*Seaplane landing area*
49	Under construction		*Work in progress*
50			*Under construction*
†51			*Work projected*
(Gd)	Subm ruins		*Submerged ruins*

H. Topography (Artificial Features)

Small-scale chart
1 *Road* (Rd) *or Highway* (Hy)

20 50 95
†(Ha) *Highway markers*

2 *Track, Footpath, or Trail*

M & L S RR
Same grade Ry. above Ry. below
3 *Railway* (Ry) *(single or double track); Railroad* (RR)

3a *Tramway*

3b *Railway station*

3c *Tunnel (railroad or road)*

3d *Embankment, Levee*

3e *Cutting*

†3f *Causeway*

OVERHEAD POWER CABLE
AUTHORIZED CL 140 FT
TOWER TOWER
4 *Overhead power cable* (OVHD PWR CAB)

5 *Power transmission line*

5a *Power transmission mast*

Tel
6 *Prominent telegraph or telephone line*

7 *Aqueduct; Water pipe*

Viaduct
8 *Viaduct*

Pipeline
†8a *Oil pipeline*

Pile Pile Piling Piling Post
†9 *Pile; Piling; Post (above MHW) (See L-59, O-30)*

MAST Mast
9a *Mast*

10 *Highway (See H-1)*

11 *Sewer*

12 *Culvert*

Canal Lock
Ditch Sluice
(Tidegate, Floodgate)
†13 *Canal; Ditch; Lock; Sluice (point upstream)*

Small-scale chart
†14 *Bridge* (BR) *in general*

14a *Stone, concrete bridge (Same as H-14)*

14b *Wooden bridge (Same as H-14)*

14c *Iron bridge (Same as H-14)*

14d *Suspension bridge (Same as H-14)*

15 *Drawbridge (in general)*

16 *Swing bridge (Same as H-15)*

16a *Lift bridge*

16b *Weighbridge or Bascule bridge*

17 *Pontoon bridge*

17a *Footbridge*

18 *Transporter bridge (Same as H-14)*

VERT CL 6 FT
18a *Bridge clearance, vertical*

HOR CL 28 FT
18b *Bridge clearance, horizontal*

Ferry Ferry
On small-scale chart
19 *Ferry* (Fy)

Cable ferry
†(Hb) *Cable ferry*

20 *Ford*

21 *Dam*

22 *Fence*

23 *Training wall*

Log boom
24 *Log boom*

I. Buildings and Structures (see General Remarks)

No.	Symbol	Abbreviation	Meaning
1			*City or Town (large scale)*
(Ia)	# o		*City or Town (small scale)*
2			*Suburb*
3		Vil	*Village*
3a			*Buildings in general*
4		Cas	*Castle*
5			*House*
6			*Villa*
7			*Farm*
8		Ch	*Church*
8a		Cath	*Cathedral*
8b	SPIRE	Spire	*Spire; Steeple*
9			*Roman Catholic Church*
†10			*Temple*
11			*Chapel*
†12			*Mosque*
†12a			*Minaret*
(Ib)			*Moslem Shrine*
†13			*Marabout*
†14		Pag	*Pagoda*
†15			*Buddhist Temple; Joss-House*
†15a			*Shinto Shrine*
16			*Monastery; Convent*
17			*Calvary; Cross*
17a	Cem		*Cemetery, Non-Christian*
18	Cem		*Cemetery, Christian*
18a			*Tomb*
19			*Fort (actual shape charted)*
†20			*Battery*
21			*Barracks*
22			*Powder magazine*
23	Airport		*Airplane landing field*
24	Airport		*Airport, large scale (See P-13)*
(Ic)			*Airport, military (small scale)*
†(Id)			*Airport, civil (small scale)*
25			*Mooring mast*
26	King St	St	*Street*
26a	Locust Ave	Ave	*Avenue*
†26b	Grand Blvd	Blvd	*Boulevard*
27		Tel	*Telegraph*
28		Tel Off	*Telegraph office*
29		P O	*Post office*
30		Govt Ho	*Government house*
31			*Town hall*
32		Hosp	*Hospital*
33			*Slaughterhouse*
34		Magz	*Magazine*
34a			*Warehouse; Storehouse*
35	MON	Mon	*Monument*
36	CUP	Cup	*Cupola*
37	ELEV	Elev	*Elevator; Lift*
(Ie)		Elev	*Elevation; Elevated*
38			*Shed*
39			*Zinc roof*
40	Ruins	Ru	*Ruins*
41	TR	Tr	*Tower*
†(If)	ABAND LT HO		*Abandoned lighthouse*
42	WINDMILL		*Windmill*
†43			*Watermill*
43a	WINDMOTOR		*Windmotor*
44	CHY	Chy	*Chimney; Stack*
45	S'PIPE	S'pipe	*Water tower; Standpipe*
46			*Oil tank*
47		Facty	*Factory*
48			*Saw mill*
49			*Brick kiln*
50			*Mine; Quarry*
51	Well		*Well*
52			*Cistern*
53	TANK	Tk	*Tank*
54			*Noria*
55			*Fountain*

I. Buildings and Structures (continued)

No.	Symbol	Abbreviation	Meaning
61		Inst	*Institute*
62			*Establishment*
63			*Bathing establishment*
64		Ct Ho	*Courthouse*
65		Sch	*School*
(Ig)		H S	*High school*
(Ih)		Univ	*University*
66	■ ▨ □	Bldg	*Building*
67		Pav	*Pavilion*
68			*Hut*
69			*Stadium*
70		T	*Telephone*
71	⊕ ●		*Gas tank; Gasometer*

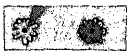
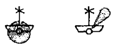
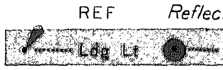
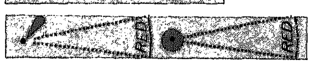
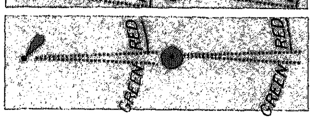
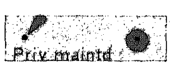
No.	Symbol	Abbreviation	Meaning
72	⊙ GAB	°Gab	*Gable*
73			*Wall*
†74			*Pyramid*
†75			*Pillar*
†76			*Oil derrick*
(Ii)		Ltd	*Limited*
(Ij)		Apt	*Apartment*
(Ik)		Cap	*Capitol*
(Il)		Co	*Company*
(Im)		Corp	*Corporation*
(In)	⊙		*Landmark (conspicuous object)*
(Io)	○		*Landmark (position approx.)*

J. Miscellaneous Stations

No.	Symbol	Abbreviation	Meaning
1		Sta	*Any kind of station*
2		Sta	*Station*
3	C G		*Coast Guard station (Similar to Lifesaving Sta.)*
(Ja)	⊙ C G WALLIS SANDS		*Coast Guard station (when landmark)*
†4	⊙ LOOK TR		*Lookout station; Watch tower*
5			*Lifeboat station*
6	LS S		*Lifesaving station (See J-3)*
7		Rkt Sta	*Rocket station*
8	⊙ PIL STA		*Pilot station*
9		Sig Sta	*Signal station*
10		Sem	*Semaphore*
11		S Sig Sta	*Storm signal station*
12			*Weather signal station*
(Jb)	⊙ W B SIG STA		*Weather Bureau signal station*

No.	Symbol	Abbreviation	Meaning
13			*Tide signal station*
14			*Stream signal station*
15			*Ice signal station*
16			*Time signal station*
†16a			*Manned oceanographic station*
†16b			*Unmanned oceanographic station*
17			*Time ball*
18			*Signal mas*
19	⊙ FS ⊙ FP °FS °FP		*Flagstaff; Flagpol*
†19a	⊙ F TR	°F Tr	*Flag tower*
20			*Signal*
21		Obsy	*Observatory*
22		Off	*Office*
(Jc)	°BELL		*Bell (on land)*
(Jd)	°HECP		*Harbor entrance control post*

K. (new optional symbol) Lights

No.	Symbol / Abbreviation	Description
†1	☆	*Position of light*
2	Lt	*Light*
†(Ka)		*Riprap surrounding light*
3	Lt Ho	*Lighthouse*
4	AERO AERO	*Aeronautical light (See F-22)*
4a		*Marine and air navigation light*
5	Bn Bn	*Light beacon*
6		*Light vessel; Lightship*
8		*Lantern*
9		*Street lamp*
10	REF	*Reflector*
11	 Ldg Lt	*Leading light*
12		*Sector light*
13		*Directional light*
14		*Harbor light*
15		*Fishing light*
16		*Tidal light*
17		*Private light (maintained by private interests; to be used with caution)*
21	F	*Fixed light*
22	Occ	*Occulting light*
23	Fl	*Flashing light*
†23a	E Int	*Isophase light (equal interval)*
24	Qk Fl	*Quick flashing (scintillating) light*
25	Int Qk Fl I Qk Fl	*Interrupted quick flashing light*
25a	S Fl	*Short flashing light*
26	Alt	*Alternating light*
27	Gp Occ	*Group occulting light*
28	Gp Fl	*Group flashing light*
28a	S-L Fl	*Short-long flashing light*
28b		*Group short flashing light*
29	F Fl	*Fixed and flashing light*
30	F Gp Fl	*Fixed and group flashing light*
†30a	Mo	*Morse code light*
31	Rot	*Revolving or Rotating light*
41		*Period*
42		*Every*
43		*With*
44		*Visible (range)*
(Kb)	M	*Nautical mile (See E-11)*
(Kc)	m; min	*Minutes (See E-2)*
(Kd)	sec	*Seconds (See E-3)*
45	Fl	*Flash*
46	Occ	*Occultation*
46a		*Eclipse*
47	Gp	*Group*
48	Occ	*Intermittent light*
49	*SEC*	*Sector*
50		*Color of sector*
51	Aux	*Auxiliary light*
52		*Varied*
61	Vi	*Violet*
62		*Purple*
63	Bu	*Blue*
64	G	*Green*
65	Or	*Orange*
66	R	*Red*
67	W	*White*
67a	Am	*Amber*
68	*OBSC*	*Obscured light*
†68a	*Fog Det Lt*	*Fog detector light (See N-Nb)*

K. Lights (continued)

69		*Unwatched light*
70	Occas	*Occasional light*
71	Irreg	*Irregular light*
72	Prov	*Provisional light*
73	Temp	*Temporary light*
(Ke)	D; Destr	*Destroyed*
74	Exting	*Extinguished light*
75		*Faint light*
76		*Upper light*
77		*Lower light*
78		*Rear light*
79		*Front light*
80	Vert	*Vertical lights*
81	Hor	*Horizontal lights*
(Kf)	VB	*Vertical beam*
(Kg)	*RGE*	*Range*
(Kh)	Exper	*Experimental light*
(Ki)	TRLB	*Temporarily replaced by lighted buoy showing the same characteristics*
(Kj)	TRUB	*Temporarily replaced by unlighted buoy*
(Kk)	TLB	*Temporary lighted buoy*
(Kl)	TUB	*Temporary unlighted buoy*

L. Buoys and Beacons (see General Remarks)

1	*Position of buoy*
2	*Light buoy*
3	*Bell buoy*
3a	*Gong buoy*
4	*Whistle buoy*
5	*Can or Cylindrical buoy*
6	*Nun or Conical buoy*
7	*Spherical buoy*
8	*Spar buoy*
†8a	*Pillar or Spindle buoy*
9	*Buoy with topmark (ball) (see L-70)*
10	*Barrel or Ton buoy*
(La)	*Color unknown*
(Lb)	*Float*
12	*Lightfloat*
13	*Outer or Landfall buoy*
14	*Fairway buoy (BWVS)*
14a	*Mid-channel buoy (BWVS)*
†15	*Starboard-hand buoy (entering from seaward)*
16	*Port-hand buoy (entering from seaward)*
17	*Bifurcation buoy (RBHB)*
18	*Junction buoy (RBHB)*
19	*Isolated danger buoy (RBHB)*
20	*Wreck buoy (RBHB or G)*
20a	*Obstruction buoy (RBHB or G)*
21	*Telegraph-cable buoy*
22	*Mooring buoy (colors of mooring buoys never carried)*
22a	*Mooring*
22b	*Mooring buoy with telegraphic communications*
22c	*Mooring buoy with telephonic communications*
23	*Warping buoy*
24	*Quarantine buoy*
†24a	*Practice area buoy*
25	*Explosive anchorage buoy*
25a	*Aeronautical anchorage buoy*
26	*Compass adjustment buoy*
27	*Fish trap (area) buoy (BWHB)*
27a	*Spoil ground buoy*
†28	*Anchorage buoy (marks limits)*
†29	*Private aid to navigation (buoy) (maintained by private interests, use with caution)*

L. Buoys and Beacons (continued)

30			Temporary buoy (See Ki,j,k,l)
30a			Winter buoy
31		HB	Horizontal stripes or bands
32		VS	Vertical stripes
33		Chec	Checkered
†33a		Diag	Diagonal bands
41		W	White
42		B	Black
43		R	Red
44		Y	Yellow
45		G	Green
46		Br	Brown
47		Gy	Gray
48		Bu	Blue
†48a		Am	Amber
†48b		Or	Orange
51			Floating beacon
52	RW Bn / W Bn / R Bn		Fixed beacon (unlighted or daybeacon)
52	Bn		Black beacon
52	Bn		Color unknown
†(Lc)	MARKER / Marker		Private aid to navigation
53		Bn	Beacon, in general (See L-52)
54			Tower beacon

55			Cardinal marking system
56	Deviation Bn		Compass adjustment beacon
57			Topmarks (See L-9, 70)
58			Telegraph-cable (landing) beacon
†59	Piles / Piles		Piles (See O-30, H-9)
†59			Stakes
†59	Stumps		Stumps (See O-30)
†59			Perches
61	CAIRN	Cairn	Cairn
62			Painted patches
63			Landmark (conspicuous object) (See D-2)
(Ld)			Landmark (position approximate)
64		REF	Reflector
65	MARKER		Range targets, markers
(Le)	W Or / W Or		Special-purpose buoys
†66			Oil installation buoy
†67			Drilling platform (See O-0b, O-0c)
70	Note:		TOPMARKS on buoys and beacons may be shown on charts of foreign waters. The abbreviation for black is not shown adjacent to buoys or beacons.
(Lf)	Ra Ref		Radar reflector (See M-13)

M. Radio and Radar Stations

1	°R Sta	*Radio telegraph station*
2	°R T	*Radio telephone station*
3	R Bn	*Radiobeacon*
4	R Bn	*Circular radiobeacon*
5	R D	*Directional radiobeacon; Radio range*
6		*Rotating loop radiobeacon*
7	R D F	*Radio direction finding station*
(Ma)	TELEM ANT	*Telemetry antenna*
†(Mb)	R RELAY MAST	*Radio relay mast*
†(Mc)	MICRO TR	*Microwave tower*
9	R MAST	*Radio mast*
	R TR	*Radio tower*
†9a	TV TR	*Television mast; Television tower*
10	R TR (WBAL) 1090 Kc	*Radio broadcasting station (commercial)*
10a	°R Sta	*Q.T.G. Radio station*
11	Ra	*Radar station*

12	Racon	*Radar responder beacon*
13	Ra Ref	*Radar reflector (See L-Lf)*
14	Ra (conspic)	*Radar conspicuous object*
14a		*Ramark*
15	D F S	*Distance finding station (synchronized signals)*
†16	AERO R Bn 302	*Aeronautical radiobeacon*
†17	° Decca Sta	*Decca station*
†18	○ Loran Sta Venice	*Loran station (name)*
†19	CONSOL Bn 190 Kc MMF	*Consol (Consolan) station*
(Md)	AERO R Rge 342	*Aeronautical radio range*
(Me)	Ra Ref Calibration Bn	*Radar calibration beacon*
(Mf)	LORAN TR SPRING ISLAND	*Loran tower (name)*
†(Mg)	R TR F R Lt	*Obstruction light*

N. Fog Signals

1	Fog Sig	*Fog-signal station*
2		*Radio fog-signal station*
3	*GUN*	*Explosive fog signal*
4		*Submarine fog signal*
5	*SUB-BELL*	*Submarine fog bell (action of waves)*
6	*SUB-BELL*	*Submarine fog bell (mechanical)*
7	*SUB-OSC*	*Submarine oscillator*
8	*NAUTO*	*Nautophone*
9	*DIA*	*Diaphone*
10	*GUN*	*Fog gun*
11	*SIREN*	*Fog siren*
12	*HORN*	*Fog trumpet*

13	*HORN*	*Fog horn*
†13a	*HORN*	*Electric fog horn*
14	*BELL*	*Fog bell*
15	*WHIS*	*Fog whistle*
16	*HORN*	*Reed horn*
17	*GONG*	*Fog gong*
†18		*Submarine sound signal not connected to the shore (See N-5, 6, 7)*
†18a		*Submarine sound signal connected to the shore (See N-5, 6, 7)*
(Na)	*HORN*	*Typhon*
(Nb)	*Fog Det Lt*	*Fog detector light (See K 68a)*

O. Dangers

(25)

1 Rock which does not cover (elevation above MHW) (See General Remarks)

Uncov 2 ft   Uncov 2 ft

(2)   (2)

2 Rock which covers and uncovers, with height in feet above chart (sounding) datum

3 Rock awash at the level of chart (sounding) datum

When rock of O-2 or O-3 is considered a danger to navigation

†4 Sunken rock dangerous to surface navigation

5 Rk

5 Shoal sounding on isolated rock (replaces symbol)

†6 Sunken rock not dangerous to surface navigation (more than 11 fathoms over rock)

21 Rk   21 Wk   21 Obstr

6a Sunken danger with depth cleared by wire drag (in feet or fathoms)

Reef

7 Reef of unknown extent

Sub Vol

8 Submarine volcano

Discol Water

9 Discolored water

Coral   Co   Co   Co

10 Coral reef, detached (uncovers at sounding datum)

Co   Reef Line

Coral or Rocky reef, covered at sounding datum (See A-11d, 11g)

11 Wreck showing any portion of hull or superstructure (above sounding datum)

Masts

12 Wreck with only masts visible (above sounding datum)

13 Old symbols for wrecks

13a Wreck always partially submerged

†14 Sunken wreck dangerous to surface navigation (less than 11 fathoms over wreck) (See O-6a)

5½ Wk

15 Wreck over which depth is known

21 Wk

†15a Wreck with depth cleared by wire drag

16 Sunken wreck, not dangerous to surface navigation

Foul

17 Foul ground

Tide Rips

18 Overfalls or Tide rips — Symbol used only in small areas

Eddies

19 Eddies — Symbol used only in small areas

Kelp

20 Kelp, Seaweed — Symbol used only in small areas

21	Bk	Bank
22	Shl	Shoal
23	Rf	Reef (See A-11d, 11g; O-10)
23a		Ridge
24	Le	Ledge

25 Breakers (See A-12)

26 Sunken rock (depth unknown)

When rock is considered a danger to navigation

5½ Obstr

27 Obstruction

28 Wreck (See O-11 to 16)

Wreckage   Wks

29 Wreckage

29a Wreck remains (dangerous only for anchoring)

Subm piles

30 Submerged piling (See H-9, L-59)

Snags   Stumps

30a Snags; Submerged stumps (See L-59)

31 Lesser depth possible

32	Uncov	Dries (See A-10; O-2, 10)
33	Cov	Covers (See O-2, 10)
34	Uncov	Uncovers (See A-10; O-2, 10)

3 Rep (1958)

Reported (with date)

Eagle Rk (rep 1958)

35 Reported (with name and date)

36	Discol	Discolored (See O-9)
37		Isolated danger

†38 Limiting danger line

rky

39 Limit of rocky area

41	PA	Position approximate
42	PD	Position doubtful
43	ED	Existence doubtful
44	P Pos	Position
45	D	Doubtful
†46		Unexamined

Subm Crib   Crib (above water)

(Oa) Crib

Platform (lighted) HORN

(Ob) Offshore platform (unnamed)

Hazel (lighted) HORN

(Oc) Offshore platform (named)

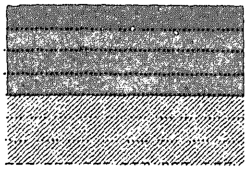
P. Various Limits, etc.

No.	Symbol	Description
1		Leading line, Range line
2		Transit
3		In line with
4		Limit of sector
5		Channel, Course, Track recommended (marked by buoys or beacons) (See P-21)
(Pa)		Alternate course
†6		Radar guided track
7		Submarine cable (power, telegraph, telephone, etc.)
7a		Submarine cable area
†7b		Abandoned submarine cable (includes disused cable)
†8		Submarine pipeline
8a		Submarine pipeline area
9		Maritime limit in general
†(Pb)		Limit of restricted area
10		Limit of fishing zone (fish trap areas)
†(Pc)		U. S. Harbor Line
11		Limit of dumping ground, spoil ground (See P-9; G-13)
12		Anchorage limit
13		Limit of airport (See I-23, 24)
†13a		Limit of military practice areas
14		Limit of sovereignty (Territorial waters)
15		Customs boundary
16		International boundary (also State boundary)
17		Stream limit
18		Ice limit
19		Limit of tide
20		Limit of navigation
†21		Course recommended (not marked by buoys or beacons) (See P-5)
22		District or province limit
23		Reservation line
24	COURSE 053°00' TRUE; MARKERS; MARKERS	Measured distance
25		Prohibited area (See G-12, 46)
†(Pd)		Shipping safety fairway
†(Pe)		Directed traffic lanes
†(Pf)	Obstruction (fish haven)	Fish haven (fishing reef)

Q. Soundings

No.	Symbol	Description
1	SD	Doubtful sounding
2	65	No bottom found
3		Out of position
4		Least depth in narrow channels
5	30 FEET APR 1968	Dredged channel (with controlling depth indicated)
6	24 FEET MAY 1968	Dredged area
7		Swept channel (See Q-9)
8	6	Drying (or uncovering) heights; in feet above chart (sounding) datum
9	17; 119	Swept area, not adequately sounded (shown by green tint)
9a	29; 23; 3; 22; 8; 30; 18; 21; 7	Swept area adequately sounded (swept by wire drag to depth indicated)
†10		Hair-line depth figures
10a	8_2 19	Figures for ordinary soundings
11	8_2 19	Soundings taken from foreign charts
12	8_2 19	Soundings taken from older surveys (or smaller scale chts)
13	8_2 19	Echo soundings
14	8_2 19	Sloping figures (See Q-12)
15	8_2 19	Upright figures (See Q-10a)
†16	(25) (2)	Bracketed figures (See O-1, 2)
17	5	Underlined sounding figures (See Q-8)
18	3_2 6_1	Soundings expressed in fathoms and feet
†22		Unsounded area
(Qa)	8 5 2ft	Stream

R. Depth Contours and Tints (see General Remarks)

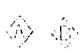
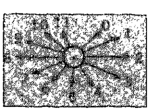


Feet	Fathoms	Feet	Fathoms	
0	0	300	50	
6	1	600	100	
12	2	1,200	200	
18	3	1,800	300	
24	4	2,400	400	
30	5	3,000	500	
36	6	6,000	1,000	
60	10	12,000	2,000	
120	20	18,000	3,000	
180	30	Or continuous lines, with values		5 (blue or black) 100
240	40			

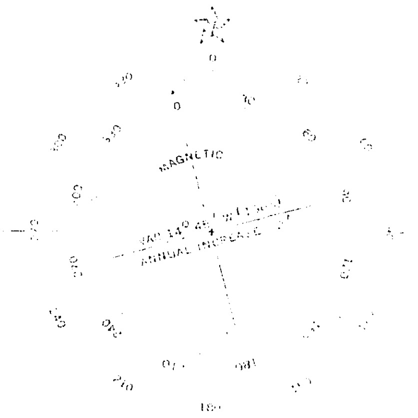
S. Quality of the Bottom

†1	*Grd*	*Ground*	24	*Oys*	*Oysters*	50	*spk*	*Speckled*
2	*S*	*Sand*	25	*Ms*	*Mussels*	51	*gty*	*Gritty*
3	*M*	*Mud; Muddy*	26	*Spg*	*Sponge*	†52	*dec*	*Decayed*
4	*Oz*	*Ooze*	†27	*K*	*Kelp*	53	*fly*	*Flinty*
5	*Ml*	*Marl*	28	*Wd*	*Sea-weed*	54	*glac*	*Glacial*
6	*Cl*	*Clay*		*Grs*	*Grass*	†55	*ten*	*Tenacious*
7	*G*	*Gravel*	†29	*Stg*	*Sea-tangle*	56	*wh*	*White*
8	*Sn*	*Shingle*	†31	*Spi*	*Spicules*	57	*bk*	*Black*
9	*P*	*Pebbles*	32	*Fr*	*Foraminifera*	58	*vi*	*Violet*
10	*St*	*Stones*	33	*Gl*	*Globigerina*	59	*bu*	*Blue*
11	*Rk; rky*	*Rock; Rocky*	34	*Di*	*Diatoms*	60	*gn*	*Green*
11a	*Blds*	*Boulders*	35	*Rd*	*Radiolaria*	61	*yl*	*Yellow*
12	*Ck*	*Chalk*	36	*Pt*	*Pteropods*	62	*or*	*Orange*
12a	*Ca*	*Calcareous*	37	*Po*	*Polyzoa*	63	*rd*	*Red*
13	*Qz*	*Quartz*	†38	*Cir*	*Cirripeda*	64	*br*	*Brown*
†13a	*Sch*	*Schist*	†38a	*Fu*	*Fucus*	65	*ch*	*Chocolate*
14	*Co*	*Coral*	†38b	*Ma*	*Mattes*	66	*gy*	*Gray*
(Sa)	*Co Hd*	*Coral head*	39	*fne*	*Fine*	67	*lt*	*Light*
15	*Mds*	*Madrepores*	40	*crs*	*Coarse*	68	*dk*	*Dark*
16	*Vol*	*Volcanic*	41	*sft*	*Soft*			
(Sb)	*Vol Ash*	*Volcanic ash*	42	*hrd*	*Hard*	†70	*vard*	*Varied*
17	*La*	*Lava*	43	*stf*	*Stiff*	†71	*unev*	*Uneven*
18	*Pm*	*Pumice*	44	*sml*	*Small*	†*(Sc)*	*S/M*	*Surface layer and Under layer*
19	*T*	*Tufa*	45	*lrg*	*Large*			
20	*Sc*	*Scoriae*	46	*stk*	*Sticky*			
21	*Cn*	*Cinders*	47	*brk*	*Broken*			
†*21a*		*Ash*	47a	*grd*	*Ground (Shells)*	76		*Fresh water springs in sea-bed*
22	*Mn*	*Manganese*	†48	*rt*	*Rotten*			
23	*Sh*	*Shells*	†49	*str*	*Streaky*			

T. Tides and Currents

1	*HW*	*High water*
1a	*HHW*	*Higher high water*
2	*LW*	*Low water*
(Ta)	*LWD*	*Low water datum*
2a	*LLW*	*Lower low water*
3	*MTL*	*Mean tide level*
4	*MSL*	*Mean sea level*
4a		*Elevation of mean sea level above chart (sounding) datum*
5		*Chart datum (datum for sounding reduction)*
6	*Sp*	*Spring tide*
7	*Np*	*Neap tide*
†*7a*	*MHW*	*Mean high water*
8	*MHWS*	*Mean high water springs*
8a	*MHWN*	*Mean high water neaps*
8b	*MHHW*	*Mean higher high water*
†*8c*	*MLW*	*Mean low water*
9	*MLWS*	*Mean low water springs*
9a	*MLWN*	*Mean low water neaps*
9b	*MLLW*	*Mean lower low water*
10	*ISLW*	*Indian spring low water*
11		*High water full and change (vulgar establishment of the port)*
12		*Low water full and change*
13		*Mean establishment of the port*
13a		*Establishment of the port*
14		*Unit of height*
15		*Equinoctial*
16		*Quarter; Quadrature*
17	*Str*	*Stream*
18	2 kn	*Current, general, with rate*
19	2 kn	*Flood stream (current) with rate*
20	2 kn	*Ebb stream (current) with rate*
21	Tide gauge	*Tide gauge; Tidepole; Automatic tide gauge*
23	*vel*	*Velocity; Rate*
24	*kn*	*Knots*
25	*ht*	*Height*
26		*Tide*
27		*New moon*
28		*Full moon*
29		*Ordinary*
30		*Syzygy*
31	*fl*	*Flood*
32		*Ebb*
33		*Tidal stream diagram*
34		*Place for which tabulated tidal stream data are given*
35		*Range (of tide)*
36		*Phase lag*
(Tb)		*Current diagram, with explanatory note*

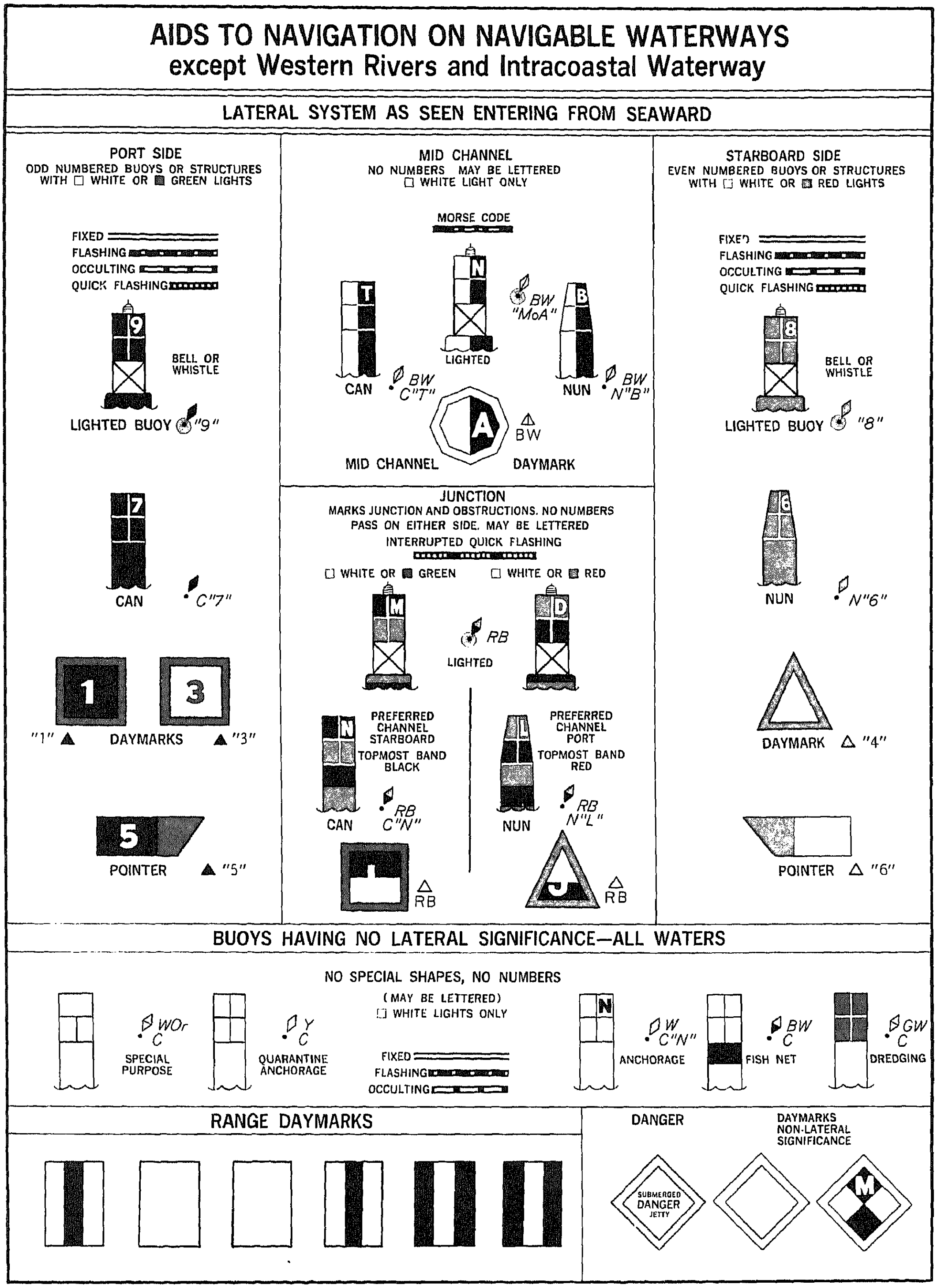
U. Compass



Compass Rose

The outer circle is in degrees with zero at true north. The inner circles are in points and degrees with the arrow indicating magnetic north.

1	N	*North*
2	E	*East*
3	S	*South*
4	W	*West*
5	NE	*Northeast*
6	SE	*Southeast*
7	SW	*Southwest*
8	NW	*Northwest*
9	N	*Northern*
10	E	*Eastern*
11	S	*Southern*
12	W	*Western*
21	brg	*Bearing*
†22	T	*True*
23	mag	*Magnetic*
24	var	*Variation*
25		*Annual change*
25a		*Annual change nil*
26		*Abnormal variation; Magnetic attraction*
27	deg	*Degrees (See E-20)*
28	dev	*Deviation*


AIDS TO NAVIGATION ON NAVIGABLE WATERWAYS
except Western Rivers and Intracoastal Waterway
LATERAL SYSTEM AS SEEN ENTERING FROM SEAWARD
PORT SIDE
ODD NUMBERED BUOYS OR STRUCTURES WITH □ WHITE OR ■ GREEN LIGHTS
FIXED
FLASHING
OCCULTING
QUICK FLASHING
9
BELL OR WHISTLE
LIGHTED BUOY "9"
7
CAN
C"7"
1
3
"1" ▲ DAYMARKS ▲ "3"
5
POINTER ▲ "5"
MID CHANNEL
NO NUMBERS MAY BE LETTERED
□ WHITE LIGHT ONLY
MORSE CODE
T
N
BW "MoA"
B
LIGHTED
CAN
BW C"T"
NUN
BW N"B"
A
BW
MID CHANNEL DAYMARK
JUNCTION
MARKS JUNCTION AND OBSTRUCTIONS. NO NUMBERS
PASS ON EITHER SIDE. MAY BE LETTERED
INTERRUPTED QUICK FLASHING
□ WHITE OR ■ GREEN
□ WHITE OR ■ RED
M
D
RB
LIGHTED
N
PREFERRED CHANNEL STARBOARD
TOPMOST BAND BLACK
CAN
RB C"N"
L
PREFERRED CHANNEL PORT
TOPMOST BAND RED
NUN
RB N"L"
RB
J
RB
STARBOARD SIDE
EVEN NUMBERED BUOYS OR STRUCTURES WITH □ WHITE OR ■ RED LIGHTS
FIXED
FLASHING
OCCULTING
QUICK FLASHING
8
BELL OR WHISTLE
LIGHTED BUOY "8"
6
NUN
N"6"
DAYMARK △ "4"
POINTER △ "6"
BUOYS HAVING NO LATERAL SIGNIFICANCE—ALL WATERS
NO SPECIAL SHAPES, NO NUMBERS
(MAY BE LETTERED)
□ WHITE LIGHTS ONLY
WOr C
SPECIAL PURPOSE
Y C
QUARANTINE ANCHORAGE
FIXED
FLASHING
OCCULTING
N
W C"N"
ANCHORAGE
BW C
FISH NET
GW C
DREDGING
RANGE DAYMARKS
DANGER
DAYMARKS NON-LATERAL SIGNIFICANCE
SUBMERGED DANGER JETTY
M

Appendix B

USEFUL PHYSICAL LAWS AND TRIGONOMETRIC FUNCTIONS.

A. Kepler's Laws

1. The orbits of the planets are ellipses with the sun at a common focus.
2. The straight line joining the sun and a planet sweeps over equal areas in equal intervals of time.
3. The squares of the orbital (sidereal) periods of any two planets are proportional to the cubes of their mean distances from the sun.

B. Newton's Laws of Motion

1. A body at rest or in uniform motion will remain at rest or in uniform motion unless some external force is applied to it.
2. When a body is acted upon by a constant force, its resulting acceleration is proportional to the force, and inversely proportional to the mass.
3. To every force there is an equal and opposite reaction force.

C. Newton's Law of Gravitation

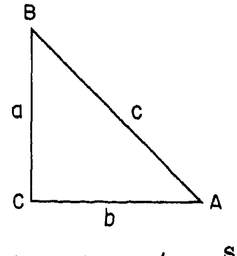
(Universal Law of Gravitation)

Every particle of matter attracts every other particle with a force that varies directly as the product of their masses and inversely as the square of the distance between them.

D. Foucault's Law

A spinning body tends to swing around so as to place its axis parallel to the axis of an impressed force, such that its direction of rotation is the same as that of the impressed force.

E. Trigonometric functions



1. Sine A = $a/c = \frac{\text{side opposite}}{\text{hypotenuse}}$

Consine $A = b/c = \frac{\text{side adjacent}}{\text{hypotenuse}}$

Tangent $A = a/b = \frac{\text{side opposite}}{\text{side adjacent}}$

Cotangent $A = b/a = \frac{\text{side adjacent}}{\text{side opposite}}$

Secant $A = c/b = \frac{\text{hypotenuse}}{\text{side adjacent}}$

Cosecant $A = c/a = \frac{\text{hypotenuse}}{\text{side opposite}}$

2. Versed sine A = 1 - cosine A
   Co-versed sine A = 1 - sine A
   Haversine A = 1/2 (1 - cosine A)

3. The cosecant is the reciprocal of the sine.
   The secant is the reciprocal of the cosine.
   The cotangent is the reciprocal of the tangent.
   The tangent equals the sine divided by the cosine.

4. The complement of an angle equals 90° - that angle.
   The supplement of an angle equals 180° - that angle.
   The explement of an angle equals 360° - that angle.

5. The sine of an angle is the cosine of its complement.
   The tangent of an angle is the cotangent of its complement.
   The secant of an angle is the cosecant of its complement.

Appendix C-1

MAYPORT, FLA., 1970

TIMES AND HEIGHTS OF HIGH AND LOW WATERS

JULY						AUGUST						SEPTEMBER					
DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.
1	0024	0.0	16	0536	3.7	1	0136	0.2	16	0100	-0.3	1	0212	0.3	16	0212	-0.5
W	0630	3.7	TH	1136	-0.4	SA	0748	3.9	SU	0712	4.8	TU	0836	4.7	W	0836	6.0
	1218	-0.3		1818	5.0		1324	0.0		1312	-0.7		1418	0.3		1436	-0.4
	1900	4.9					2006	4.9		1942	5:7		2048	4.9		2100	5.7
2	0112	0.0	17	0030	-0.1	2	0212	0.1	17	0148	-0.5	2	0242	0.3	17	0300	-0.4
TH	0718	3.7	F	0636	3.9	SU	0824	4.0	M	0806	5.1	W	0906	4.8	TH	0924	6.0
	1300	-0.2		1230	-0.6		1406	0.1		1406	-0.8		1454	0.4		1530	-0.2
	1942	4.9		1912	5.3		2042	4.8		2036	5.7		2118	4.8		2148	5.5
3	0154	0.0	18	0124	-0.4	3	0242	0.1	18	0236	-0.7	3	0312	0.3	18	0342	-0.3
F	0806	3.7	SA	0730	4.2	M	0900	4.1	TU	0900	5.3	TH	0942	4.8	F	1018	5.9
	1342	-0.2		1324	-0.8		1442	0.1		1454	-0.7		1530	0.5		1618	0.1
	2024	4.8		2006	5.4		2118	4.7		2124	5.6		2154	4.6		2236	5.2
4	0236	0.0	19	0212	-0.6	4	0318	0.1	19	0324	-0.7	4	0342	0.3	19	0430	0.0
SA	0848	3.7	SU	0824	4.4	TU	0936	4.2	W	0948	5.5	F	1018	4.8	SA	1106	5.7
	1424	-0.1		1418	-0.9		1518	0.2		1548	-0.6		1606	0.6		1712	0.5
	2106	4.7		2054	5.5		2148	4.6		2212	5.4		2224	4.5		2324	4.8
5	0312	0.0	20	0300	-0.7	5	0348	0.1	20	0412	-0.6	5	0418	0.4	20	0524	0.3
SU	0924	3.7	M	0918	4.7	W	1012	4.2	TH	1042	5.4	SA	1054	4.8	SU	1200	5.4
	1506	0.0		1512	-0.8		1554	0.3		1642	-0.3		1648	0.8		1812	0.8
	2142	4.6		2148	5.4		2224	4.4		2306	5.1		2300	4.3			
6	0348	0.0	21	0354	-0.8	6	0424	0.1	21	0506	-0.4	6	0454	0.4	21	0018	4.4
M	1006	3.7	TU	1012	4.8	TH	1048	4.2	F	1136	5.3	SU	1136	4.8	M	0618	0.7
	1542	0.1		1606	-0.7		1636	0.4		1742	0.0		1736	0.9		1300	5.1
	2218	4.4		2236	5.3		2254	4.2		2354	4.7		2342	4.1		1918	1.1
7	0424	0.1	22	0442	-0.7	7	0454	0.2	22	0554	-0.1	7	0536	0.5	22	0118	4.1
TU	1042	3.7	W	1106	4.9	F	1124	4.3	SA	1230	5.2	M	1218	4.8	TU	0718	1.0
	1624	0.3		1706	-0.5		1718	0.6		1842	0.4		1830	1.1		1400	4.9
	2254	4.3		2330	5.0		2330	4.1								2024	1.3
8	0500	0.1	23	0536	-0.6	8	0530	0.2	23	0048	4.4	5	0030	4.0	23	0224	4.0
W	1124	3.8	TH	1200	4.9	SA	1206	4.3	SU	0654	0.2	TU	0630	0.6	W	0824	1.1
	1706	0.4		1806	-0.3		1806	0.7		1330	5.0		1318	4.8		1500	4.8
	2330	4.1								1948	0.7		1930	1.2		2130	1.3
9	0536	0.1	24	0024	4.7	9	0012	3.9	24	0148	4.0	9	0130	3.9	24	0330	4.0
TH	1206	3.8	F	0630	-0.4	SU	0612	0.3	M	0754	0.4	W	0736	0.7	TH	0930	1.2
	1754	0.5		1300	4.8		1254	4.3		1430	4.8		1418	4.8		1600	4.8
				1906	0.0		1900	0.8		2054	0.8		2042	1.1		2224	1.2
10	0012	3.9	25	0118	4.3	10	0100	3.7	25	0254	3.8	10	0242	4.0	25	0430	4.1
F	0618	0.2	SA	0724	-0.3	M	0706	0.3	TU	0854	0.6	TH	0848	0.6	F	1030	1.1
	1248	3.9		1354	4.7		1348	4.4		1536	4.7		1530	5.0		1700	4.8
	1842	0.6		2012	0.2		2000	0.9		2200	0.9		2149	0.9		2312	1.0
11	0054	3.7	26	0218	4.0	11	0154	3.6	26	0400	3.8	11	0348	4.2	26	0524	4.4
SA	0700	0.2	SU	0824	-0.1	TU	0806	0.3	W	0954	0.6	F	1000	0.4	SA	1118	0.9
	1336	3.9		1500	4.7		1448	4.5		1636	4.7		1636	5.2		1748	4.9
	1936	0.7		2118	0.4		2106	0.8		2300	0.8		2248	0.6		2354	0.8
12	0142	3.6	27	0318	3.8	12	0254	3.6	27	0500	3.8	12	0500	4.6	27	0612	4.6
SU	0754	0.1	M	0924	0.0	W	0906	0.2	TH	1054	0.6	SA	1100	0.1	SU	1200	0.8
	1424	4.1		1600	4.7		1548	4.7		1730	4.8		1736	5.5		1830	5.0
	2036	0.7		2224	0.4		2212	0.6		2348	0.7		2348	0.2			
13	0230	3.5	28	0418	3.6	13	0406	3.7	28	0554	4.0	13	0600	5.0	28	0030	0.7
M	0842	0.1	TU	1018	0.0	TH	1012	0.0	F	1142	0.5	SU	1200	-0.2	M	0648	4.9
	1524	4.3		1700	4.7		1654	4.9		1818	4.9		1830	5.7		1242	0.7
	2142	0.6		2318	0.4		2312	0.4								1906	5.1
14	0330	3.4	29	0518	3.6	14	0512	4.0	29	0030	0.6	14	0036	-0.1	29	0100	0.6
TU	0942	-0.1	W	1112	0.1	F	1118	-0.2	SA	0642	4.2	M	0654	5.4	TU	0724	5.1
	1618	4.5		1754	4.8		1754	5.2		1224	0.4		1254	-0.4		1318	0.6
	2242	0.4								1900	5.0		1924	5.8		1942	5.1
15	0436	3.5	30	0012	0.3	15	0006	0.0	30	0106	0.4	15	0124	-0.3	30	0136	0.5
W	1036	-0.2	TH	0612	3.7	SA	0618	4.4	SU	0718	4.4	TU	0748	5.8	W	0800	5.2
	1718	4.7		1200	0.1		1212	-0.5		1306	0.4		1348	-0.5		1354	0.5
	2336	0.1		1842	4.8		1854	5.5		1936	5.0		2012	5.8		2018	5.0
			31	0054	0.2				31	0142	0.3						
			F	0700	3.8				M	0800	4.6						
				1242	0.0					1342	0.3						
				1924	4.9					2012	5.0						

TIME MERIDIAN 75° W. 0000 IS MIDNIGHT. 1200 IS NOON.
HEIGHTS ARE RECKONED FROM THE DATUM OF SOUNDINGS ON CHARTS OF THE LOCALITY WHICH IS MEAN LOW WATER.

TIDAL DIFFERENCES AND OTHER CONSTANTS

No.	PLACE	POSITION Lat.	POSITION Long.	DIFFERENCES Time High water	DIFFERENCES Time Low water	DIFFERENCES Height High water	DIFFERENCES Height Low water	RANGES Mean	RANGES Spring	Mean Tide Level
		° ′	° ′	h. m.	h. m.	feet	feet	feet	feet	feet
	GEORGIA and FLORIDA	N.	W.							
	Cumberland Sound		on	**SAVANNAH RIVER ENT., p.106**						
				Time meridian, 75°W.						
2821	St. Marys Entrance, north jetty-----	30 43	81 26	+0 15	+0 15	-1.1	0.0	5.8	6.8	2.9
2823	Crooked River entrance-------------	30 51	81 29	+1 23	+1 12	-0.1	0.0	6.8	8.0	3.4
2825	Harrietts Bluff, Crooked River------	30 52	81 35	+2 09	+2 12	-0.5	0.0	6.4	7.5	3.2
2827	St. Marys, St. Marys River----------	30 43	81 33	+1 21	+1 13	-0.9	0.0	6.0	7.0	3.0
2829	Crandall, St. Marys River-----------	30 43	81 37	+2 10	+1 59	-1.8	0.0	5.1	6.0	2.5
				on MAYPORT, p.114						
2831	Fernandina Beach (outer coast)------	30 38	81 26	-0 18	-0 01	+1.2	0.0	5.7	6.7	2.8
2833	Fernandina Beach, Amelia River------	30 40	81 28	+0 32	+0 16	+1.5	0.0	6.0	7.0	3.0
2835	Chester, Bells River---------------	30 41	81 32	+0 49	+0 41	+1.9	0.0	6.4	7.5	3.2
2837	S. A. L. RR. bridge, Kingsley Creek-	30 38	81 29	+0 59	+0 43	+1.5	0.0	6.0	7.0	3.0
	FLORIDA									
	Nassau Sound and Fort George River									
2839	Nassau Sound-----------------------	30 31	81 27	-0 03	+0 06	+0.9	0.0	5.4	6.3	2.7
2841	Amelia City, South Amelia River-----	30 35	81 28	+0 54	+1 03	+1.1	0.0	5.6	6.6	2.8
2843	Nassauville, Nassau River-----------	30 34	81 31	+1 04	+1 37	+0.3	0.0	4.8	5.6	2.4
2845	Mink Creek entrance, Nassau River---	30 32	81 34	+1 58	+2 32	-0.6	0.0	3.9	4.6	1.9
2847	Halfmoon Island, highway bridge-----	30 34	81 36	+3 00	+3 21	-1.0	0.0	3.5	4.1	1.7
2849	Sawpit Creek entrance---------------	30 31	81 27	-0 02	+0 30	+0.5	0.0	5.0	5.8	2.5
2851	Fort George Island, Fort George R---	30 26	81 26	+0 29	+0 39	+0.3	0.0	4.8	5.6	2.4
	St. Johns River									
2853	South Jetty------------------------	30 24	81 23	-0 23	-0 17	+0.4	0.0	4.9	5.7	2.4
2855	MAYPORT----------------------------	30 24	81 26	Daily predictions				4.5	5.3	2.3
2857	Pablo Creek bascule bridge----------	30 19	81 26	+1 39	+1 15	*0.64	*0.64	2.9	3.4	1.4
2859	Fulton-----------------------------	30 23	81 30	+0 29	+0 42	-1.1	0.0	3.4	4.0	1.7
2861	Dame Point-------------------------	30 23	81 33	+0 46	+0 55	*0.67	*0.67	3.0	3.5	1.5
2863	Phoenix Park (Cummers Mill)---------	30 23	81 38	+0 58	+1 25	*0.44	*0.44	2.0	2.3	1.0
2865	Jacksonville (Dredge Depot)---------	30 21	81 37	+1 24	+1 50	*0.44	*0.44	2.0	2.3	1.0
2867	Jacksonville (RR. bridge)-----------	30 19	81 40	+2 06	+2 13	*0.27	*0.27	1.2	1.4	0.6
2869	Ortega River entrance---------------	30 17	81 42	+2 27	+2 50	*0.20	*0.20	0.9	1.1	0.5
2871	Orange Park------------------------	30 10	81 42	+3 49	+4 14	*0.16	*0.16	0.7	0.8	0.3
2873	Green Cove Springs------------------	30 00	81 40	+5 26	+6 13	*0.18	*0.18	0.8	0.9	0.4
2875	East Tocoi-------------------------	29 51	81 34	+6 47	+7 18	*0.22	*0.22	1.0	1.2	0.5
2877	Bridgeport-------------------------	29 45	81 34	+6 58	+7 32	*0.24	*0.24	1.1	1.3	0.5
2879	Palatka----------------------------	29 39	81 38	+7 26	+8 21	*0.27	*0.27	1.2	1.4	0.6
2881	Welaka-----------------------------	29 29	81 40	+7 46	+8 25	*0.11	*0.11	0.5	0.6	0.2
	FLORIDA, East Coast									
2883	Atlantic Beach----------------------	30 20	81 24	-0 25	-0 18	+0.7	0.0	5.2	6.0	2.6
2885	St. Augustine Inlet-----------------	29 53	81 17	-0 21	-0 01	0.0	0.0	4.5	5.3	2.2
2887	St. Augustine-----------------------	29 54	81 18	+0 14	+0 43	-0.3	0.0	4.2	5.0	2.1
2889	Daytona Beach (ocean)---------------	29 14	81 00	-0 33	-0 32	-0.4	0.0	4.1	4.9	2.0
				on MIAMI HBR. ENT., p.118						
2891	Ponce de Leon Inlet-----------------	29 04	80 55	+0 06	+0 20	-0.2	0.0	2.3	2.7	1.2
2893	Cape Canaveral----------------------	28 26	80 34	-0 41	-0 41	+1.0	0.0	3.5	4.1	1.8
2894	Sebastian Inlet---------------------	27 52	80 27	-0 23	-0 31	-0.3	0.0	2.2	2.6	1.1
2895	Fort Pierce Inlet (breakwater)------	27 28	80 17	-0 14	-0 18	+0.1	0.0	2.6	3.0	1.3
2897	Fort Pierce (City Dock)-------------	27 27	80 19	+1 51	+2 11	*0.28	*0.28	0.7	0.8	0.3
2899	St. Lucie Inlet (jetty)-------------	27 10	80 09	-0 20	-0 21	+0.1	0.0	2.6	3.0	1.3
2901	Sewall Point, St. Lucie River-------	27 11	80 12	+1 34	+2 33	*0.40	*0.40	1.0	1.2	0.5
2903	Jupiter Inlet (near lighthouse)-----	26 57	80 05	+1 04	+1 38	*0.52	*0.52	1.3	1.5	0.6
2905	Port of Palm Beach, Lake Worth------	26 46	80 03	0 00	+0 12	+0.1	0.0	2.6	3.1	1.3
2907	Palm Beach (ocean)------------------	26 43	80 02	-0 21	-0 18	+0.3	0.0	2.8	3.3	1.4
2909	Hillsboro Inlet---------------------	26 15	80 05	+0 13	+0 36	-0.2	0.0	2.3	2.7	1.2
	Fort Lauderdale									
2911	Bahia Mar Yacht Club----------	26 07	80 06	+0 28	+0 32	-0.2	0.0	2.3	2.8	1.1
2913	Andrews Ave. bridge, New River-	26 07	80 09	+1 06	+1 28	-0.7	0.0	1.8	2.2	0.9

*Ratio.

Appendix C-3

TABLE 3.—HEIGHT OF TIDE AT ANY TIME

Duration of rise or fall, see footnote	Time from the nearest high water or low water														
h. m.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
4 00	0 08	0 16	0 24	0 32	0 40	0 48	0 56	1 04	1 12	1 20	1 28	1 36	1 44	1 52	2 00
4 20	0 09	0 17	0 26	0 35	0 43	0 52	1 01	1 09	1 18	1 27	1 35	1 44	1 53	2 01	2 10
4 40	0 09	0 19	0 28	0 37	0 47	0 56	1 05	1 15	1 24	1 33	1 43	1 52	2 01	2 11	2 20
5 00	0 10	0 20	0 30	0 40	0 50	1 00	1 10	1 20	1 30	1 40	1 50	2 00	2 10	2 20	2 30
5 20	0 11	0 21	0 32	0 43	0 53	1 04	1 15	1 25	1 36	1 47	1 57	2 08	2 19	2 29	2 40
5 40	0 11	0 23	0 34	0 45	0 57	1 08	1 19	1 31	1 42	1 53	2 05	2 16	2 27	2 39	2 50
6 00	0 12	0 24	0 36	0 48	1 00	1 12	1 24	1 36	1 48	2 00	2 12	2 24	2 36	2 48	3 00
6 20	0 13	0 25	0 38	0 51	1 03	1 16	1 29	1 41	1 54	2 07	2 19	2 32	2 45	2 57	3 10
6 40	0 13	0 27	0 40	0 53	1 07	1 20	1 33	1 47	2 00	2 13	2 27	2 40	2 53	3 07	3 20
7 00	0 14	0 28	0 42	0 56	1 10	1 24	1 38	1 52	2 06	2 20	2 34	2 48	3 02	3 16	3 30
7 20	0 15	0 29	0 44	0 59	1 13	1 28	1 43	1 57	2 12	2 27	2 41	2 56	3 11	3 25	3 40
7 40	0 15	0 31	0 46	1 01	1 17	1 32	1 47	2 03	2 18	2 33	2 49	3 04	3 19	3 35	3 50
8 00	0 16	0 32	0 48	1 04	1 20	1 36	1 52	2 08	2 24	2 40	2 56	3 12	3 28	3 44	4 00
8 20	0 17	0 33	0 50	1 07	1 23	1 40	1 57	2 13	2 30	2 47	3 03	3 20	3 37	3 53	4 10
8 40	0 17	0 35	0 52	1 09	1 27	1 44	2 01	2 19	2 36	2 53	3 11	3 28	3 45	4 03	4 20
9 00	0 18	0 36	0 54	1 12	1 30	1 48	2 06	2 24	2 42	3 00	3 18	3 36	3 54	4 12	4 30
9 20	0 19	0 37	0 56	1 15	1 33	1 52	2 11	2 29	2 48	3 07	3 25	3 44	4 03	4 21	4 40
9 40	0 19	0 39	0 58	1 17	1 37	1 56	2 15	2 35	2 54	3 13	3 33	3 52	4 11	4 31	4 50
10 00	0 20	0 40	1 00	1 20	1 40	2 00	2 20	2 40	3 00	3 20	3 40	4 00	4 20	4 40	5 00
10 20	0 21	0 41	1 02	1 23	1 43	2 04	2 25	2 45	3 06	3 27	3 47	4 08	4 29	4 49	5 10
10 40	0 21	0 43	1 04	1 25	1 47	2 08	2 29	2 51	3 12	3 33	3 55	4 16	4 37	4 59	5 20

Range of tide, see footnote	Correction to height														
Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
1.5	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8
2.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
2.5	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2
3.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.5
3.5	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.8
4.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0
4.5	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2
5.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.7	2.0	2.2	2.5
5.5	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.4	1.6	1.9	2.2	2.5	2.8
6.0	0.0	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.0
6.5	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.6	1.9	2.2	2.6	2.9	3.2
7.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.4	1.8	2.1	2.4	2.8	3.1	3.5
7.5	0.0	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.5	1.9	2.2	2.6	3.0	3.4	3.8
8.0	0.0	0.1	0.2	0.3	0.5	0.8	1.0	1.3	1.6	2.0	2.4	2.8	3.2	3.6	4.0
8.5	0.0	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.1	2.5	2.9	3.4	3.8	4.2
9.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.2	2.7	3.1	3.6	4.0	4.5
9.5	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.0	2.4	2.8	3.3	3.8	4.3	4.8
10.0	0.0	0.1	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5	4.0	4.5	5.0
10.5	0.0	0.1	0.3	0.5	0.7	1.0	1.3	1.7	2.2	2.6	3.1	3.6	4.2	4.7	5.2
11.0	0.0	0.1	0.3	0.5	0.7	1.1	1.4	1.8	2.3	2.8	3.3	3.8	4.4	4.9	5.5
11.5	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.4	2.9	3.4	4.0	4.6	5.1	5.8
12.0	0.0	0.1	0.3	0.5	0.8	1.1	1.5	2.0	2.5	3.0	3.6	4.1	4.8	5.4	6.0
12.5	0.0	0.1	0.3	0.5	0.8	1.2	1.6	2.1	2.6	3.1	3.7	4.3	5.0	5.6	6.2
13.0	0.0	0.1	0.3	0.6	0.9	1.2	1.7	2.2	2.7	3.2	3.9	4.5	5.1	5.8	6.5
13.5	0.0	0.1	0.3	0.6	0.9	1.3	1.7	2.2	2.8	3.4	4.0	4.7	5.3	6.0	6.8
14.0	0.0	0.2	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.5	4.2	4.8	5.5	6.3	7.0
14.5	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.4	3.0	3.6	4.3	5.0	5.7	6.5	7.2
15.0	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.5	3.1	3.8	4.4	5.2	5.9	6.7	7.5
15.5	0.0	0.2	0.4	0.7	1.0	1.5	2.0	2.6	3.2	3.9	4.6	5.4	6.1	6.9	7.8
16.0	0.0	0.2	0.4	0.7	1.1	1.5	2.1	2.6	3.3	4.0	4.7	5.5	6.3	7.2	8.0
16.5	0.0	0.2	0.4	0.7	1.1	1.6	2.1	2.7	3.4	4.1	4.9	5.7	6.5	7.4	8.2
17.0	0.0	0.2	0.4	0.7	1.1	1.6	2.2	2.8	3.5	4.2	5.0	5.9	6.7	7.6	8.5
17.5	0.0	0.2	0.4	0.8	1.2	1.7	2.2	2.9	3.6	4.4	5.2	6.0	6.9	7.8	8.8
18.0	0.0	0.2	0.4	0.8	1.2	1.7	2.3	3.0	3.7	4.5	5.3	6.2	7.1	8.1	9.0
18.5	0.1	0.2	0.5	0.8	1.2	1.8	2.4	3.1	3.8	4.6	5.5	6.4	7.3	8.3	9.2
19.0	0.1	0.2	0.5	0.8	1.3	1.8	2.4	3.1	3.9	4.8	5.6	6.6	7.5	8.5	9.5
19.5	0.1	0.2	0.5	0.8	1.3	1.9	2.5	3.2	4.0	4.9	5.8	6.7	7.7	8.7	9.8
20.0	0.1	0.2	0.5	0.9	1.3	1.9	2.6	3.3	4.1	5.0	5.9	6.9	7.9	9.0	10.0

Obtain from the predictions the high water and low water, one of which is before and the other after the time for which the height is required. The difference between the times of occurrence of these tides is the duration of rise or fall, and the difference between their heights is the range of tide for the above table. Find the difference between the nearest high or low water and the time for which the height is required.

Enter the table with the duration of rise or fall, printed in heavy-faced type, which most nearly agrees with the actual value, and on that horizontal line find the time from the nearest high or low water which agrees most nearly with the corresponding actual difference. The correction sought is in the column directly below, on the line with the range of tide.

When the nearest tide is high water, subtract the correction.

When the nearest tide is low water, add the correction.

Appendix D-1

ST. JOHNS RIVER ENTRANCE, FLA., 1970

F-FLOOD, DIR. 275° TRUE   E-EBB, DIR. 100° TRUE

MARCH

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1		0136	1.9F	16	0012	0230	1.5F
SU	0430	0706	1.9E	M	0530	0900	1.4E
	1212	1406	1.1F		1312	1500	0.9F
	1612	1918	2.2E		1730	2030	1.5E
	2342						
2		0236	1.9F	17	0112	0330	1.5F
M	0536	0818	1.9E	TU	0630	1036	1.5E
	1312	1506	1.2F		1406	1600	1.0F
	1724	2024	2.2E		1830	2148	1.5E
3	0054	0336	2.1F	18	0206	0430	1.6F
TU	0636	0930	2.0E	W	0718	1118	1.6E
	1406	1606	1.4F		1454	1654	1.2F
	1836	2136	2.3E		1924	2248	1.7E
4	0200	0436	2.3F	19	0254	0518	1.7F
W	0736	1036	2.2E	TH	0806	1142	1.8E
	1454	1706	1.8F		1530	1742	1.4F
	1942	2248	2.5E		2018	2336	1.8E
5	0300	0536	2.5F	20	0342	0600	1.8F
TH	0830	1142	2.5E	F	0848	1206	1.9E
	1542	1800	2.1F		1606	1818	1.7F
	2042	2354	2.7E		2106		
6	0354	0624	2.6F	21		0012	2.0E
F	0924	1230	2.7E	SA	0424	0642	1.8F
	1624	1854	2.4F		0930	1230	2.1E
	2142				1642	1900	1.9F
					2148		
7		0048	2.9E	22		0048	2.2E
SA	0448	0718	2.7F	SU	0506	0718	1.9F
	1012	1318	2.8E		1006	1300	2.2E
	1712	1942	2.6F		1712	1942	2.0F
	2230				2224		
8		0136	2.9E	23		0118	2.3E
SU	0536	0806	2.6F	M	0542	0800	1.8F
	1054	1400	2.9E		1042	1330	2.3E
	1754	2030	2.8F		1742	2018	2.1F
	2324				2306		
9		0224	2.9E	24		0200	2.4E
M	0624	0854	2.5F	TU	0624	0842	1.8F
	1136	1442	2.9E		1112	1406	2.4E
	1842	2118	2.7F		1812	2100	2.2F
					2348		
10	0012	0312	2.8E	25		0236	2.5E
TU	0718	0936	2.2F	W	0706	0924	1.6F
	1224	1518	2.8E		1148	1442	2.5E
	1924	2206	2.6F		1836	2148	2.2F
11	0100	0400	2.5E	26	0030	0318	2.5E
W	0812	1024	1.9F	TH	0748	1006	1.5F
	1306	1600	2.6E		1224	1524	2.5E
	2018	2254	2.4F		1912	2230	2.2F
12	0148	0442	2.2E	27	0118	0400	2.4E
TH	0906	1112	1.6F	F	0836	1054	1.3F
	1348	1642	2.3E		1306	1612	2.4E
	2112	2342	2.1F		2000	2324	2.1F
13	0242	0530	1.9E	28	0206	0454	2.3E
F	1012	1206	1.3F	SA	0936	1148	1.2F
	1436	1730	2.0E		1354	1700	2.3E
	2206				2054		
14		0036	1.9F	29		0018	2.0F
SA	0336	0624	1.7E	SU	0306	0548	2.1E
	1112	1300	1.1F		1042	1242	1.2F
	1524	1818	1.8E		1454	1800	2.2E
	2312				2212		
15		0130	1.7F	30		0112	1.9F
SU	0430	0730	1.5E	M	0406	0648	2.0E
	1218	1400	0.9F		1142	1342	1.2F
	1624	1918	1.6E		1600	1900	2.1E
					2336		
				31		0218	1.9F
				TU	0512	0754	2.0E
					1242	1448	1.4F
					1718	2012	2.1E

APRIL

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1	0048	0318	2.0F	16	0136	0348	1.4F
W	0612	0912	2.1E	TH	0636	0948	1.7E
	1336	1548	1.7F		1412	1618	1.4F
	1824	2130	2.2E		1854	2206	1.7E
2	0148	0418	2.1F	17	0230	0436	1.5F
TH	0712	1018	2.2F	F	0724	1030	1.8F
	1424	1648	2.0F		1448	1700	1.6F
	1930	2242	2.4F		1948	2300	1.9E
3	0248	0512	2.2F	18	0312	0524	1.6F
F	0806	1112	2.5F	SA	0806	1106	1.9F
	1512	1742	2.3F		1524	1748	1.8F
	2030	2342	2.6E		2036	2336	2.1E
4	0342	0606	2.3F	19	0400	0606	1.7F
SA	0854	1206	2.6E	SU	0848	1142	2.1F
	1600	1830	2.6F		1600	1830	2.1F
	2124				2118		
5		0036	2.8E	20		0018	2.2E
SU	0430	0654	2.3F	M	0442	0648	1.7F
	0942	1248	2.7E		0924	1218	2.2E
	1642	1918	2.7F		1630	1912	2.2F
	2218				2200		
6		0124	2.8E	21		0054	2.4E
M	0524	0742	2.3F	TU	0524	0730	1.7F
	1024	1330	2.8E		1006	1254	2.4E
	1724	2006	2.8F		1700	1948	2.4F
	2306				2242		
7		0212	2.7E	22		0136	2.5E
TU	0612	0830	2.1F	W	0606	0818	1.6F
	1106	1412	2.7E		1042	1336	2.5E
	1812	2048	2.7F		1730	2036	2.4F
	2348				2324		
8		0254	2.6E	23		0218	2.5E
W	0700	0912	1.9F	TH	0648	0900	1.6F
	1148	1448	2.6E		1118	1418	2.5E
	1900	2136	2.5F		1806	2118	2.4F
9	0036	0336	2.4E	24	0012	0300	2.5E
TH	0754	1000	1.7F	F	0736	0948	1.5F
	1230	1530	2.6E		1200	1500	2.5E
	1948	2224	2.3F		1854	2206	2.3F
10	0124	0418	2.2E	25	0100	0348	2.5E
F	0848	1048	1.4F	SA	0824	1036	1.4F
	1318	1612	2.2E		1248	1554	2.4F
	2036	2312	2.0F		1942	2300	2.2F
11	0212	0500	1.9E	26	0148	0436	2.4E
SA	0942	1136	1.2F	SU	0918	1130	1.4F
	1406	1654	1.9E		1348	1648	2.3F
	2136				2048	2354	2.1F
12		0006	1.8F	27	0248	0530	2.2E
SU	0300	0548	1.7E	M	1018	1224	1.4F
	1042	1230	1.1F		1448	1742	2.2E
	1500	1748	1.7E		2206		
	2236						
13		0100	1.6F	28		0054	2.0F
M	0354	0642	1.6E	TU	0342	0636	2.1E
	1142	1330	1.0F		1118	1324	1.5F
	1554	1842	1.5E		1600	1854	2.1E
	2342				2324		
14		0154	1.4F	29		0154	1.9F
TU	0448	0748	1.5E	W	0442	0742	2.1E
	1236	1430	1.0F		1212	1424	1.7F
	1700	1948	1.5E		1706	2006	2.1E
15	0042	0254	1.4F	30	0030	0254	1.9F
W	0542	0854	1.6F	TH	0542	0848	2.2E
	1324	1524	1.2F		1306	1524	1.9F
	1800	2100	1.5E		1818	2124	2.2E

TIME MERIDIAN 75° W. 0000 IS MIDNIGHT. 1200 IS NOON.

Appendix D-2

CURRENT DIFFERENCES AND OTHER CONSTANTS

No.	PLACE	POSITION: Lat.	POSITION: Long.	TIME DIFFERENCES: Slack water	TIME DIFFERENCES: Maximum current	VELOCITY RATIOS: Maximum flood	VELOCITY RATIOS: Maximum ebb	MAXIMUM CURRENTS Flood: Direction (true)	MAXIMUM CURRENTS Flood: Average velocity	MAXIMUM CURRENTS Ebb: Direction (true)	MAXIMUM CURRENTS Ebb: Average velocity
		° ′	° ′	h. m.	h. m.			deg.	knots	deg.	knots
	ST. JOHNS RIVER—Continued	N.	W.								
			on ST. JOHNS RIVER ENTRANCE, p.94 *Time meridian, 75°W.*								
5380	St. Johns Bluff	30 23	81 30	+0 05	+0 50	0.8	1.0	245	1.6	60	2.2
5385	Drummond Point, channel south of	30 25	81 36	+2 00	+2 30	0.7	0.7	230	1.3	60	1.6
5390	Phoenix Park	30 23	81 38	+2 40	+3 10	0.6	0.4	190	1.1	350	1.0
5395	Chaseville, channel near	30 23	81 37	+2 35	+3 20	0.6	0.7	150	1.1	335	1.6
5400	Quarantine Station, Long Branch	30 21	81 37	+2 30	+3 05	0.6	0.5	185	1.1	0	1.2
5405	Commodore Point, terminal channel	30 19	81 38	+2 35	+3 10	0.5	0.4	210	1.0	60	1.0
5410	Jacksonville, off Washington St	30 19	81 39	+2 20	+2 50	0.9	0.8	280	1.8	120	1.9
5415	Jacksonville, F. E. C. RR. bridge	30 19	81 40	+2 20	+3 00	0.8	0.7	240	1.6	60	1.7
5420	Winter Point	30 18	81 40	+2 55	+3 10	0.6	0.5	200	1.1	15	1.1
5425	Mandarin Point	30 09	81 41	+3 00	+3 20	0.3	0.3	180	0.6	15	0.7
5430	Red Bay Point, bridge draw	29 59	81 38	(1)	(1)	0.5	0.3	115	0.9	300	0.6
5435	Tocoi to Lake George	-----	-----	*Current too weak and variable to be predicted.*							
	FLORIDA COAST			on MIAMI HARBOR ENTRANCE, p.100							
5440	Ft. Pierce Inlet	27 28	80 18	+0 50	+0 25	1.4	1.5	250	2.6	70	3.1
5445	Lake Worth Inlet, (between jetties)	26 46	80 02	−0 10	−0 15	1.3	1.7	275	2.4	95	3.6
5450	Fort Lauderdale, New River	26 07	80 07	−0 40	−0 40	0.4	0.2	5	0.8	130	0.5
	PORT EVERGLADES										
5455	Pier 2, 1.3 miles east of	26 06	80 06	-----	-----	----	----	(2)	0.2	(2)	0.4
5460	Entrance, between jetties	26 06	80 06	−0 40	−0 55	0.3	0.3	275	0.6	95	0.7
5465	Entrance from southward (canal)	26 05	80 07	+0 20	−0 15	0.7	0.8	165	1.3	0	1.7
5470	Turning Basin	26 06	80 07	−1 15	−1 20	0.1	0.2	320	0.2	155	0.5
5475	Turning Basin, 300 yards north of	26 06	80 07	−0 40	−0 55	0.5	0.9	350	0.9	160	1.8
5480	17th Street Bridge	26 06	80 07	−0 50	−1 05	1.0	0.9	350	1.9	170	1.9
	MIAMI HARBOR										
5485	Bakers Haulover Cut	25 54	80 07	−0 10	−0 15	1.5	1.2	270	2.9	90	2.5
5490	North Jetty (east end)	25 46	80 07	−0 40	−0 35	0.4	0.6	250	0.8	105	1.3
5495	Miami Outer Bay Cut entrance	25 46	80 06	See table 5.							
5500	MIAMI HARBOR ENT. (between jetties)	25 46	80 08	Daily predictions				290	1.9	125	2.1
5503	Fowey Rocks Light, 1.5 miles SW. of	25 35	80 07	*Current too weak and variable to be predicted.*							
	FLORIDA REEFS to MIDNIGHT PASS			on KEY WEST, p.106							
5505	Caesar Creek, Biscayne Bay	25 23	80 14	−0 05	−0 05	1.2	1.0	315	1.2	125	1.8
5510	Long Key, drawbridge east of	24 50	80 46	+1 40	+1 30	1.1	0.7	0	1.1	200	1.2
5515	Long Key Viaduct	24 48	80 52	+1 50	+1 40	0.9	0.7	350	0.9	170	1.2
5520	Moser Channel, drawbridge	24 42	81 10	+1 30	+1 40	1.4	1.0	340	1.4	165	1.8
5525	Bahia Honda Harbor, bridge	24 39	81 17	+1 25	+0 50	1.4	1.2	5	1.4	180	2.1
5530	No Name Key, NE. of	24 42	81 19	+1 10	+1 10	0.7	0.5	310	0.7	140	0.9
	Key West										
5535	Main Ship Channel entrance	24 28	81 48	−0 15	0 00	0.2	0.3	40	0.2	180	0.4
5540	Main Ship Channel	24 30	81 48	(3)	(3) +0 30	(3)	0.2	65	(3)	135	0.4
5545	KEY WEST, 0.3 mi. W. of Ft. Taylor	24 33	81 49	Daily predictions				20	1.0	195	1.7
5550	0.6 mile N. of Ft. Taylor	24 34	81 49	+0 05	+0 15	0.6	0.7	40	0.6	200	1.2
5565	Turning Basin	24 34	81 48	+0 35	+0 55	0.8	0.6	50	0.8	215	1.1
5560	Northwest Channel	24 35	81 51	−0 10	−0 05	1.2	0.8	355	1.2	160	1.4
5565	Northwest Channel	24 37	81 53	−0 25	−0 20	0.6	0.4	345	0.6	170	0.6
5570	Boca Grande Channel	24 34	82 04	−0 20	−0 25	1.1	0.7	355	1.1	195	1.2
5575	New Ground†	24 39	82 25	+1 30	+1 35	0.7	0.4	70	0.7	245	0.7

[1] Flood begins, $+2^h\,35^m$; maximum flood, $+3^h\,25^m$; ebb begins, $+5^h\,00^m$; maximum ebb, $+4^h\,00^m$.

[2] Flood usually occurs in a southerly direction and the ebb in a northeastwardly direction.

[3] Times of slack are indefinite. Flood is weak and variable. Time difference is for maximum ebb.

† Current tends to rotate clockwise. At times for slack flood begins there may be a weak current flowing northward while at times for slack ebb begins there may be a weak current flowing southeastward.

Appendix D-3

TABLE 3.—VELOCITY OF CURRENT AT ANY TIME

TABLE A

Interval between slack and desired time	Interval between slack and maximum current													
	h. m. 1 20	*h. m.* 1 40	*h. m.* 2 00	*h. m.* 2 20	*h. m.* 2 40	*h. m.* 3 00	*h. m.* 3 20	*h. m.* 3 40	*h. m.* 4 00	*h. m.* 4 20	*h. m.* 4 40	*h. m.* 5 00	*h. m.* 5 20	*h. m.* 5 40
h. m.	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*
0 20	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0 40	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
1 00	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3
1 20	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
1 40	---	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4
2 00	---	---	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5
2 20	---	---	---	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6
2 40	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7
3 00	---	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7
3 20	---	---	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
3 40	---	---	---	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.9	0.9
4 00	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9	0.9
4 20	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9
4 40	---	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0
5 00	---	---	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0
5 20	---	---	---	---	---	---	---	---	---	---	---	---	1.0	1.0
5 40	---	---	---	---	---	---	---	---	---	---	---	---	---	1.0

TABLE B

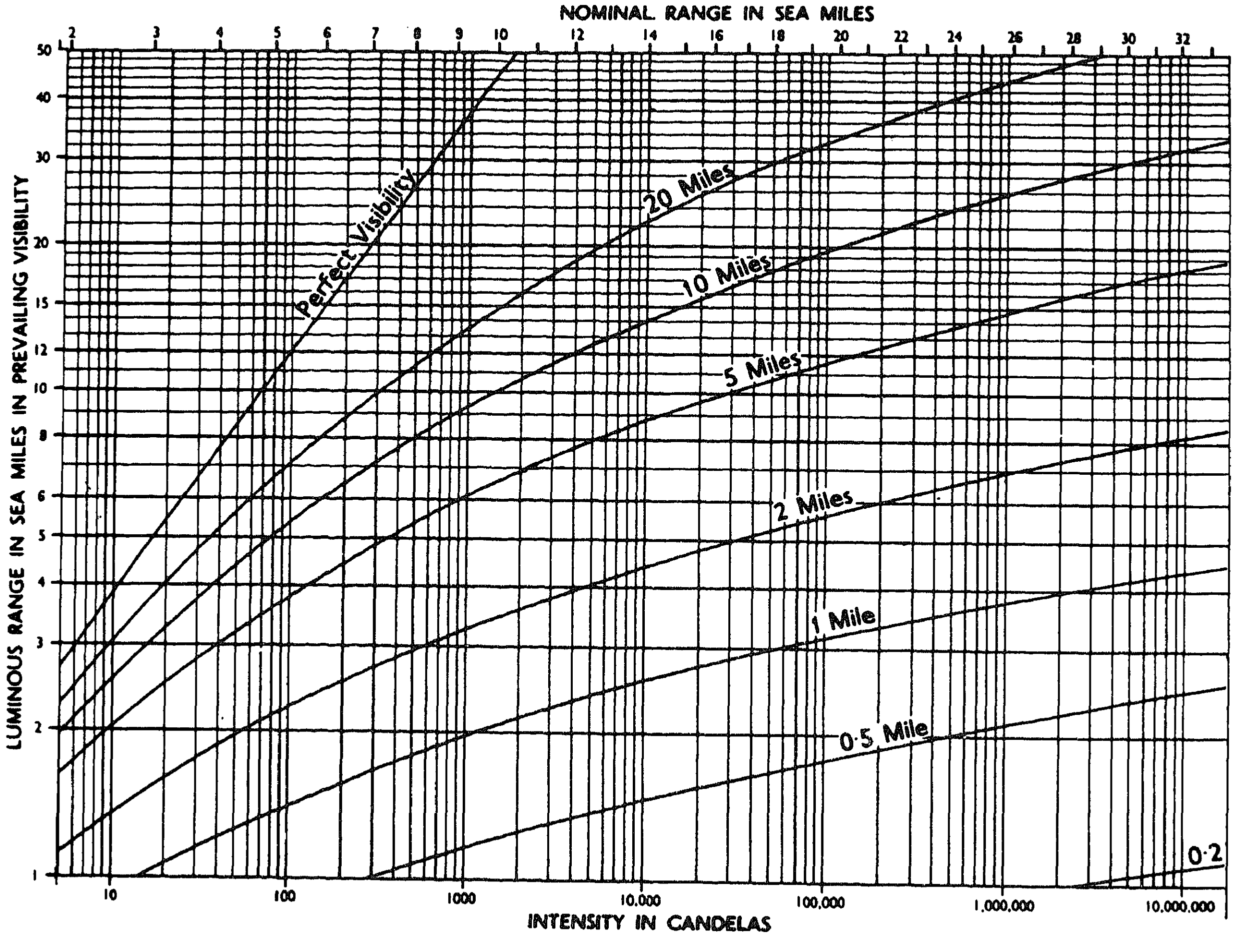
Interval between slack and desired time	Interval between slack and maximum current													
	h. m. 1 20	*h. m.* 1 40	*h. m.* 2 00	*h. m.* 2 20	*h. m.* 2 40	*h. m.* 3 00	*h. m.* 3 20	*h. m.* 3 40	*h. m.* 4 00	*h. m.* 4 20	*h. m.* 4 40	*h. m.* 5 00	*h. m.* 5 20	*h. m.* 5 40
h. m.	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*
0 20	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
0 40	0.8	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
1 00	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
1 20	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
1 40	---	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
2 00	---	---	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6
2 20	---	---	---	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
2 40	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7
3 00	---	---	---	---	---	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
3 20	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.8
3 40	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9	0.9	0.9
4 00	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9	0.9
4 20	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0	0.9
4 40	---	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0	1.0
5 00	---	---	---	---	---	---	---	---	---	---	---	1.0	1.0	1.0
5 20	---	---	---	---	---	---	---	---	---	---	---	---	1.0	1.0
5 40	---	---	---	---	---	---	---	---	---	---	---	---	---	1.0

Use Table A for all places except those listed below for Table B.
Use Table B for Cape Cod Canal, Hell Gate, Chesapeake and Delaware Canal and all stations in Table 2 which are referred to them.

1. From predictions find the time of slack water and the time and velocity of maximum current (flood or ebb), one of which is immediately before and the other after the time for which the velocity is desired.
2. Find the interval of time between the above slack and maximum current, and enter the top of Table A or B with the interval which most nearly agrees with this value.
3. Find the interval of time between the above slack and the time desired, and enter the side of Table A or B with the interval which most nearly agrees with this value.
4. Find, in the table, the factor corresponding to the above two intervals, and multiply the maximum velocity by this factor. The result will be the approximate velocity at the time desired.

Appendix E-1

LUMINOUS RANGE DIAGRAM



Appendix E-2

Distance of visibility of objects at sea:

Ht. in ft.	Naut. Mi.
1	1.1
2	1.7
3	2.0
4	2.3
5	2.5
6	2.8
7	2.9
8	3.1
9	3.5
10	3.6
11	3.8
12	4.0
13	4.2
14	4.3
15	4.4
16	4.6
17	4.7
18	4.9
19	5.0
20	5.1
21	5.3
22	5.4
23	5.5
24	5.6
25	5.7
26	5.8
27	6.0
28	6.1
29	6.2
30	6.3
31	6.4
32	6.5
33	6.6
34	6.7
35	6.8
36	6.9
37	6.9
38	7.0
39	7.1
40	7.2
41	7.3
42	7.4
43	7.5
44	7.6
45	7.7
50	8.1

Ht. in ft.	Naut. Mi.
55	8.5
60	8.9
65	9.2
70	9.6
75	9.9
80	10.3
85	10.6
90	10.9
95	11.2
100	11.5
105	11.7
110	12.0
115	12.3
120	12.6
125	12.9
130	13.1
135	13.3
140	13.6
145	13.8
150	14.1
160	14.5
170	14.9
180	15.4
190	15.8
200	16.2
210	16.6
220	17.0
230	17.4
240	17.7
250	18.2
260	18.5
270	18.9
280	19.2
290	19.6
300	19.9
310	20.1
320	20.5
330	20.8
340	21.1
350	21.5
360	21.7
370	22.1
380	22.3
390	22.7
400	22.9

Appendix F-1

1970 JANUARY 1, 2, 3 (THURS., FRI., SAT.)

G.M.T.		ARIES	VENUS −3·5		MARS +1·0		JUPITER −1·5		SATURN +0·5		STARS		
d	h	G.H.A.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	G.H.A.	Dec.	Name	S.H.A.	Dec.
		° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′		° ′	° ′
1	00	100 13·8	185 22·2	S 23 37·9	116 17·9	S 7 43·3	249 40·2	S11 08·9	69 27·8	N 9 49·3	Acamar	315 42·8	S 40 25·5
	01	115 16·3	200 21·2	37·9	131 18·6	42·6	264 42·3	09·0	84 30·2	49·3	Achernar	335 50·6	S 57 23·5
	02	130 18·8	215 20·2	37·8	146 19·3	41·8	279 44·5	09·1	99 32·7	49·3	Acrux	173 46·3	S 62 55·7
	03	145 21·2	230 19·3	. . 37·8	161 20·1	. . 41·0	294 46·6	. . 09·2	114 35·2	. . 49·4	Adhara	255 37·9	S 28 55·7
	04	160 23·7	245 18·3	37·8	176 20·8	40·3	309 48·7	09·3	129 37·7	49·4	Aldebaran	291 26·7	N 16 27·2
	05	175 26·2	260 17·3	37·8	191 21·6	39·5	324 50·9	09·4	144 40·2	49·4			
	06	190 28·6	275 16·4	S 23 37·8	206 22·3	S 7 38·8	339 53·0	S11 09·5	159 42·6	N 9 49·4	Alioth	166 49·1	N 56 07·0
	07	205 31·1	290 15·4	37·8	221 23·1	38·0	354 55·1	09·7	174 45·1	49·4	Alkaid	153 24·6	N 49 27·4
T	08	220 33·5	305 14·4	37·8	236 23·8	37·3	9 57·3	09·8	189 47·6	49·4	Al Na'ir	28 24·8	S 47 06·7
H	09	235 36·0	320 13·4	. . 37·7	251 24·6	. . 36·5	24 59·4	. . 09·9	204 50·1	. . 49·4	Alnilam	276 19·3	S 1 13·1
U	10	250 38·5	335 12·5	37·7	266 25·3	35·8	40 01·5	10·0	219 52·6	49·4	Alphard	218 28·0	S 8 31·6
R	11	265 40·9	350 11·5	37·7	281 26·0	35·0	55 03·7	10·1	234 55·0	49·4			
S	12	280 43·4	5 10·5	S 23 37·7	296 26·8	S 7 34·2	70 05·8	S11 10·2	249 57·5	N 9 49·4	Alphecca	126 38·9	N 26 48·6
D	13	295 45·9	20 09·6	37·7	311 27·5	33·5	85 07·9	10·3	265 00·0	49·4	Alpheratz	358 17·6	N 28 55·7
A	14	310 48·3	35 08·6	37·6	326 28·3	32·7	100 10·1	10·4	280 02·5	49·4	Altair	62 40·5	N 8 47·2
Y	15	325 50·8	50 07·6	. . 37·6	341 29·0	. . 32·0	115 12·2	. . 10·5	295 05·0	. . 49·4	Ankaa	353 47·8	S 42 28·3
	16	340 53·3	65 06·6	37·6	356 29·8	31·2	130 14·4	10·6	310 07·4	49·4	Antares	113 06·8	S 26 22·1
	17	355 55·7	80 05·7	37·5	11 30·5	30·5	145 16·5	10·7	325 09·9	49·5			
	18	10 58·2	95 04·7	S 23 37·5	26 31·3	S 7 29·7	160 18·6	S11 10·9	340 12·4	N 9 49·5	Arcturus	146 25·7	N 19 20·0
	19	26 00·7	110 03·7	37·5	41 32·0	28·9	175 20·8	11·0	355 14·9	49·5	Atria	108 38·7	S 68 58·5
	20	41 03·1	125 02·8	37·5	56 32·7	28·2	190 22·9	11·1	10 17·3	49·5	Avior	234 31·0	S 59 24·5
	21	56 05·6	140 01·8	. . 37·4	71 33·5	. . 27·4	205 25·0	. . 11·2	25 19·8	. . 49·5	Bellatrix	279 06·8	N 6 19·6
	22	71 08·0	155 00·8	37·4	86 34·2	26·7	220 27·2	11·3	40 22·3	49·5	Betelgeuse	271 36·4	N 7 24·3
	23	86 10·5	169 59·8	37·3	101 35·0	25·9	235 29·3	11·4	55 24·8	49·5			
2	00	101 13·0	184 58·8	S 23 37·3	116 35·7	S 7 25·2	250 31·5	S11 11·5	70 27·3	N 9 49·5	Canopus	264 10·1	S 52 40·6
	01	116 15·4	199 57·9	37·3	131 36·5	24·4	265 33·6	11·6	85 29·7	49·5	Capella	281 22·4	N 45 58·4
	02	131 17·9	214 56·9	37·2	146 37·2	23·6	280 35·7	11·7	100 32·2	49·5	Deneb	49 54·4	N 45 10·4
	03	146 20·4	229 55·9	. . 37·2	161 38·0	. . 22·9	295 37·9	. . 11·8	115 34·7	. . 49·5	Denebola	183 06·9	N 14 44·3
	04	161 22·8	244 55·0	37·1	176 38·7	22·1	310 40·0	11·9	130 37·2	49·5	Diphda	349 28·6	S 18 09·1
	05	176 25·3	259 54·0	37·1	191 39·4	21·4	325 42·2	12·0	145 39·6	49·6			
	06	191 27·8	274 53·0	S 23 37·1	206 40·2	S 7 20·6	340 44·3	S11 12·2	160 42·1	N 9 49·6	Dubhe	194 31·0	N 61 54·5
	07	206 30·2	289 52·0	37·0	221 40·9	19·8	355 46·4	12·3	175 44·6	49·6	Elnath	278 53·7	N 28 35·2
	08	221 32·7	304 51·1	37·0	236 41·7	19·1	10 48·6	12·4	190 47·1	49·6	Eltanin	91 01·9	N 51 29·3
F	09	236 35·1	319 50·1	. . 36·9	251 42·4	. . 18·3	25 50·7	. . 12·5	205 49·5	. . 49·6	Enif	34 19·5	N 9 44·2
R	10	251 37·6	334 49·1	36·9	266 43·2	17·6	40 52·9	12·6	220 52·0	49·6	Fomalhaut	16 00·1	S 29 47·1
I	11	266 40·1	349 48·2	36·8	281 43·9	16·8	55 55·0	12·7	235 54·5	49·6			
D	12	281 42·5	4 47·2	S 23 36·8	296 44·7	S 7 16·1	70 57·1	S11 12·8	250 57·0	N 9 49·6	Gacrux	172 37·7	S 56 56·5
A	13	296 45·0	19 46·2	36·7	311 45·4	15·3	85 59·3	12·9	265 59·4	49·6	Gienah	176 26·0	S 17 22·5
Y	14	311 47·5	34 45·2	36·7	326 46·2	14·5	101 01·4	13·0	281 01·9	49·6	Hadar	149 35·0	S 60 13·6
	15	326 49·9	49 44·3	. . 36·6	341 46·9	. . 13·8	116 03·6	. . 13·1	296 04·4	. . 49·6	Hamal	328 37·7	N 23 19·5
	16	341 52·4	64 43·3	36·5	356 47·7	13·0	131 05·7	13·2	311 06·9	49·7	Kaus Aust.	84 27·6	S 34 24·2
	17	356 54·9	79 42·3	36·5	11 48·4	12·3	146 07·9	13·3	326 09·3	49·7			
	18	11 57·3	94 41·4	S 23 36·4	26 49·2	S 7 11·5	161 10·0	S11 13·4	341 11·8	N 9 49·7	Kochab	137 18·7	N 74 16·3
	19	26 59·8	109 40·4	36·4	41 49·9	10·7	176 12·1	13·6	356 14·3	49·7	Markab	14 11·2	N 15 02·7
	20	42 02·3	124 39·4	36·3	56 50·7	10·0	191 14·3	13·7	11 16·8	49·7	Menkar	314 49·1	N 3 58·5
	21	57 04·7	139 38·5	. . 36·2	71 51·4	. . 09·2	206 16·4	. . 13·8	26 19·2	. . 49·7	Menkent	148 46·5	S 36 13·3
	22	72 07·2	154 37·5	36·2	86 52·1	08·5	221 18·6	13·9	41 21·7	49·7	Miaplacidus	221 46·3	S 69 35·4
	23	87 09·6	169 36·5	36·1	101 52·9	07·7	236 20·7	14·0	56 24·2	49·7			
3	00	102 12·1	184 35·5	S 23 36·0	116 53·6	S 7 06·9	251 22·9	S11 14·1	71 26·6	N 9 49·7	Mirfak	309 27·1	N 49 45·7
	01	117 14·6	199 34·6	36·0	131 54·4	06·2	266 25·0	14·2	86 29·1	49·7	Nunki	76 39·2	S 26 20·3
	02	132 17·0	214 33·6	35·9	146 55·1	05·4	281 27·2	14·3	101 31·6	49·8	Peacock	54 11·1	S 56 50·2
	03	147 19·5	229 32·6	. . 35·8	161 55·9	. . 04·7	296 29·3	. . 14·4	116 34·1	. . 49·8	Pollux	244 07·3	N 28 06·0
	04	162 22·0	244 31·7	35·7	176 56·6	03·9	311 31·4	14·5	131 36·5	49·8	Procyon	245 33·6	N 5 18·3
	05	177 24·4	259 30·7	35·7	191 57·4	03·2	326 33·6	14·6	146 39·0	49·8			
	06	192 26·9	274 29·7	S 23 35·6	206 58·1	S 7 02·4	341 35·7	S11 14·7	161 41·5	N 9 49·8	Rasalhague	96 37·2	N 12 34·6
	07	207 29·4	289 28·8	35·5	221 58·9	01·6	356 37·9	14·8	176 43·9	49·8	Regulus	208 18·0	N 12 06·8
S	08	222 31·8	304 27·8	35·4	236 59·6	00·9	11 40·0	14·9	191 46·4	49·8	Rigel	281 43·2	S 8 14·0
A	09	237 34·3	319 26·8	. . 35·4	252 00·4	7 00·1	26 42·2	. . 15·0	206 48·9	. . 49·8	Rigil Kent.	140 37·1	S 60 42·6
T	10	252 36·8	334 25·9	35·3	267 01·1	6 59·4	41 44·3	15·1	221 51·4	49·8	Sabik	102 50·4	S 15 41·5
U	11	267 39·2	349 24·9	35·2	282 01·9	58·6	56 46·5	15·3	236 53·8	49·9			
R	12	282 41·7	4 23·9	S 23 35·1	297 02·6	S 6 57·8	71 48·6	S11 15·4	251 56·3	N 9 49·9	Schedar	350 18·2	N 56 22·7
D	13	297 44·1	19 22·9	35·0	312 03·4	57·1	86 50·8	15·5	266 58·8	49·9	Shaula	97 06·8	S 37 05·1
A	14	312 46·6	34 22·0	34·9	327 04·1	56·3	101 52·9	15·6	282 01·2	49·9	Sirius	259 02·2	S 16 40·3
Y	15	327 49·1	49 21·0	. . 34·9	342 04·9	. . 55·5	116 55·1	. . 15·7	297 03·7	. . 49·9	Spica	159 05·9	S 11 00·4
	16	342 51·5	64 20·0	34·8	357 05·6	54·8	131 57·2	15·8	312 06·2	49·9	Suhail	223 16·3	S 43 18·5
	17	357 54·0	79 19·1	34·7	12 06·4	54·0	146 59·3	15·9	327 08·6	49·9			
	18	12 56·5	94 18·1	S 23 34·6	27 07·1	S 6 53·3	162 01·5	S11 16·0	342 11·1	N 9 49·9	Vega	81 01·6	N 38 45·1
	19	27 58·9	109 17·1	34·5	42 07·9	52·5	177 03·6	16·1	357 13·6	49·9	Zuben'ubi	137 41·9	S 15 55·1
	20	43 01·4	124 16·2	34·4	57 08·6	51·7	192 05·8	16·2	12 16·1	50·0			
	21	58 03·9	139 15·2	. . 34·3	72 09·4	. . 51·0	207 07·9	. . 16·3	27 18·5	. . 50·0			
	22	73 06·3	154 14·2	34·2	87 10·1	50·2	222 10·1	16·4	42 21·0	50·0			
	23	88 08·8	169 13·3	34·1	102 10·9	49·5	237 12·2	16·5	57 23·5	50·0			
Mer. Pass.		h m 17 12·3	v −1·0	d 0·1	v 0·7	d 0·8	v 2·1	d 0·1	v 2·5	d 0·0			

	S.H.A. ° ′	Mer. Pass. h m
Venus	83 45·9	11 41
Mars	15 22·7	16 13
Jupiter	149 18·5	7 17
Saturn	329 14·3	19 15

Appendix F-2

1970 JANUARY 1, 2, 3 (THURS., FRI., SAT.)

	G.M.T.	SUN G.H.A.	SUN Dec.	MOON G.H.A.	v	MOON Dec.	d	H.P.
	d h	° ′	° ′	° ′	′	° ′	′	′
	1 00	179 10·8	S 23 03·4	271 18·0	15·4	S 6 20·4	14·6	55·9
	01	194 10·5	03·2	285 52·4	15·4	6 35·0	14·6	56·0
	02	209 10·2	03·0	300 26·8	15·3	6 49·6	14·6	56·0
	03	224 09·9	. . 02·8	315 01·1	15·2	7 04·2	14·6	56·0
	04	239 09·6	02·6	329 35·3	15·2	7 18·8	14·6	56·1
	05	254 09·3	02·4	344 09·5	15·1	7 33·4	14·5	56·1
	06	269 09·0	S 23 02·2	358 43·6	15·1	S 7 47·9	14·6	56·1
	07	284 08·7	02·0	13 17·7	14·9	8 02·5	14·5	56·2
T	08	299 08·4	01·8	27 51·6	14·9	8 17·0	14·5	56·2
H	09	314 08·1	. . 01·6	42 25·5	14·9	8 31·5	14·5	56·2
U	10	329 07·8	01·4	56 59·4	14·8	8 46·0	14·5	56·3
R	11	344 07·5	01·2	71 33·2	14·6	9 00·5	14·5	56·3
S	12	359 07·2	S 23 01·0	86 06·8	14·7	S 9 15·0	14·4	56·3
D	13	14 06·9	00·8	100 40·5	14·5	9 29·4	14·4	56·4
A	14	29 06·6	00·6	115 14·0	14·5	9 43·8	14·4	56·4
Y	15	44 06·3	. . 00·4	129 47·5	14·4	9 58·2	14·4	56·4
	16	59 06·0	00·2	144 20·9	14·3	10 12·6	14·4	56·5
	17	74 05·7	23 00·0	158 54·2	14·2	10 27·0	14·3	56·5
	18	89 05·5	S 22 59·8	173 27·4	14·1	S 10 41·3	14·3	56·5
	19	104 05·2	59·6	188 00·5	14·1	10 55·6	14·3	56·6
	20	119 04·9	59·4	202 33·6	13·9	11 09·9	14·2	56·6
	21	134 04·6	. . 59·2	217 06·5	13·9	11 24·1	14·2	56·6
	22	149 04·3	58·9	231 39·4	13·8	11 38·3	14·2	56·7
	23	164 04·0	58·7	246 12·2	13·7	11 52·5	14·1	56·7
	2 00	179 03·7	S 22 58·5	260 44·9	13·6	S 12 06·6	14·1	56·8
	01	194 03·4	58·3	275 17·5	13·5	12 20·7	14·1	56·8
	02	209 03·1	58·1	289 50·0	13·4	12 34·8	14·0	56·8
	03	224 02·8	. . 57·9	304 22·4	13·3	12 48·8	14·0	56·9
	04	239 02·5	57·7	318 54·7	13·3	13 02·8	14·0	56·9
	05	254 02·2	57·4	333 27·0	13·1	13 16·8	13·9	56·9
	06	269 01·9	S 22 57·2	347 59·1	13·0	S 13 30·7	13·9	57·0
	07	284 01·6	57·0	2 31·1	12·9	13 44·6	13·8	57·0
	08	299 01·3	56·8	17 03·0	12·8	13 58·4	13·8	57·1
F	09	314 01·0	. . 56·6	31 34·8	12·7	14 12·2	13·8	57·1
R	10	329 00·8	56·3	46 06·5	12·6	14 26·0	13·6	57·1
I	11	344 00·5	56·1	60 38·1	12·5	14 39·6	13·7	57·2
D	12	359 00·2	S 22 55·9	75 09·6	12·4	S 14 53·3	13·6	57·2
A	13	13 59·9	55·7	89 41·0	12·3	15 06·9	13·5	57·3
Y	14	28 59·6	55·4	104 12·3	12·2	15 20·4	13·5	57·3
	15	43 59·3	. . 55·2	118 43·5	12·0	15 33·9	13·5	57·3
	16	58 59·0	55·0	133 14·5	11·9	15 47·4	13·3	57·4
	17	73 58·7	54·8	147 45·4	11·9	16 00·7	13·3	57·4
	18	88 58·4	S 22 54·5	162 16·3	11·7	S 16 14·0	13·3	57·5
	19	103 58·1	54·3	176 47·0	11·6	16 27·3	13·2	57·5
	20	118 57·8	54·1	191 17·6	11·4	16 40·5	13·1	57·5
	21	133 57·5	. . 53·9	205 48·0	11·4	16 53·6	13·1	57·6
	22	148 57·3	53·6	220 18·4	11·2	17 06·7	13·0	57·6
	23	163 57·0	53·4	234 48·6	11·1	17 19·7	13·0	57·6
	3 00	178 56·7	S 22 53·2	249 18·7	11·0	S 17 32·7	12·8	57·7
	01	193 56·4	52·9	263 48·7	10·8	17 45·5	12·8	57·7
	02	208 56·1	52·7	278 18·5	10·7	17 58·3	12·8	57·8
	03	223 55·8	. . 52·5	292 48·2	10·6	18 11·1	12·6	57·8
	04	238 55·5	52·2	307 17·8	10·5	18 23·7	12·6	57·9
	05	253 55·2	52·0	321 47·3	10·3	18 36·3	12·5	57·9
	06	268 54·9	S 22 51·8	336 16·6	10·2	S 18 48·8	12·4	57·9
	07	283 54·6	51·5	350 45·8	10·1	19 01·2	12·3	58·0
S	08	298 54·3	51·3	5 14·9	10·0	19 13·5	12·3	58·0
A	09	313 54·1	. . 51·0	19 43·9	9·8	19 25·8	12·1	58·1
T	10	328 53·8	50·8	34 12·7	9·7	19 37·9	12·1	58·1
U	11	343 53·5	50·6	48 41·4	9·5	19 50·0	12·0	58·1
R	12	358 53·2	S 22 50·3	63 09·9	9·4	S 20 02·0	11·9	58·2
D	13	13 52·9	50·1	77 38·3	9·3	20 13·9	11·8	58·2
A	14	28 52·6	49·8	92 06·6	9·1	20 25·7	11·7	58·3
Y	15	43 52·3	. . 49·6	106 34·7	9·0	20 37·4	11·7	58·3
	16	58 52·0	49·3	121 02·7	8·8	20 49·1	11·5	58·3
	17	73 51·7	49·1	135 30·5	8·7	21 00·6	11·4	58·4
	18	88 51·5	S 22 48·9	149 58·2	8·6	S 21 12·0	11·3	58·4
	19	103 51·2	48·6	164 25·8	8·4	21 23·3	11·2	58·5
	20	118 50·9	48·4	178 53·2	8·3	21 34·5	11·1	58·5
	21	133 50·6	. . 48·1	193 20·5	8·2	21 45·6	11·0	58·5
	22	148 50·3	47·9	207 47·7	8·0	21 56·6	10·9	58·6
	23	163 50·0	47·6	222 14·7	7·8	22 07·5	10·8	58·6
		S.D. 16·3	*d* 0·2	S.D. 15·3		15·6		15·9

Lat.	Twilight Naut.	Twilight Civil	Sunrise	Moonrise 1	Moonrise 2	Moonrise 3	Moonrise 4
°	h m	h m	h m	h m	h m	h m	h m
N 72	08 23	10 40	■	01 23	03 47	■	■
N 70	08 04	09 48	■	01 13	03 21	06 21	■
68	07 49	09 16	■	01 04	03 01	05 24	■
66	07 37	08 52	10 26	00 58	02 46	04 51	08 02
64	07 26	08 33	09 49	00 52	02 33	04 27	06 43
62	07 17	08 18	09 22	00 47	02 23	04 08	06 07
60	07 09	08 05	09 02	00 43	02 14	03 52	05 41
N 58	07 02	07 54	08 45	00 39	02 06	03 39	05 20
56	06 55	07 44	08 31	00 35	01 59	03 28	05 04
54	06 49	07 35	08 19	00 32	01 53	03 18	04 50
52	06 44	07 28	08 08	00 30	01 47	03 10	04 37
50	06 39	07 20	07 58	00 27	01 42	03 02	04 26
45	06 28	07 05	07 38	00 22	01 32	02 46	04 04
N 40	06 18	06 52	07 22	00 18	01 23	02 32	03 46
35	06 09	06 40	07 08	00 14	01 15	02 21	03 31
30	06 00	06 30	06 56	00 10	01 09	02 11	03 18
20	05 44	06 11	06 35	00 05	00 58	01 54	02 56
N 10	05 28	05 54	06 17	00 00	00 48	01 40	02 37
0	05 12	05 38	06 00	24 39	00 39	01 26	02 19
S 10	04 53	05 20	05 43	24 30	00 30	01 13	02 01
20	04 31	05 00	05 24	24 20	00 20	00 59	01 43
30	04 02	04 35	05 03	24 09	00 09	00 42	01 22
35	03 44	04 21	04 50	24 03	00 03	00 33	01 09
40	03 22	04 03	04 35	23 56	24 22	00 22	00 55
45	02 52	03 41	04 18	23 48	24 10	00 10	00 38
S 50	02 08	03 12	03 56	23 38	23 55	24 18	00 18
52	01 42	02 57	03 45	23 34	23 48	24 08	00 08
54	01 02	02 40	03 33	23 29	23 40	23 57	24 23
56	////	02 19	03 20	23 24	23 32	23 45	24 06
58	////	01 51	03 04	23 18	23 22	23 30	23 46
S 60	////	01 08	02 44	23 11	23 11	23 14	23 21

Lat.	Sunset	Twilight Civil	Twilight Naut.	Moonset 1	Moonset 2	Moonset 3	Moonset 4
°	h m	h m	h m	h m	h m	h m	h m
N 72	■	13 27	15 45	10 16	09 25	■	■
N 70	■	14 19	16 03	10 30	09 54	08 35	■
68	■	14 52	16 18	10 40	10 15	09 33	■
66	13 41	15 15	16 31	10 49	10 32	10 08	08 49
64	14 19	15 34	16 41	10 57	10 46	10 33	10 09
62	14 45	15 49	16 51	11 03	10 58	10 53	10 46
60	15 06	16 02	16 59	11 09	11 08	11 09	11 12
N 58	15 23	16 14	17 06	11 14	11 17	11 23	11 33
56	15 37	16 24	17 12	11 19	11 25	11 35	11 51
54	15 49	16 33	17 18	11 23	11 32	11 46	12 05
52	16 00	16 41	17 24	11 26	11 39	11 55	12 18
50	16 09	16 48	17 29	11 30	11 44	12 03	12 30
45	16 30	17 03	17 40	11 37	11 57	12 21	12 53
N 40	16 46	17 17	17 50	11 43	12 07	12 36	13 13
35	17 00	17 28	17 59	11 49	12 16	12 49	13 29
30	17 12	17 38	18 08	11 53	12 24	13 00	13 43
20	17 32	17 56	18 24	12 01	12 38	13 19	14 06
N 10	17 51	18 13	18 40	12 09	12 50	13 35	14 27
0	18 08	18 30	18 56	12 16	13 01	13 51	14 46
S 10	18 25	18 48	19 15	12 22	13 12	14 06	15 06
20	18 43	19 08	19 37	12 30	13 24	14 23	15 27
30	19 05	19 32	20 05	12 38	13 38	14 42	15 51
35	19 17	19 47	20 23	12 43	13 46	14 54	16 05
40	19 32	20 05	20 46	12 48	13 55	15 07	16 22
45	19 50	20 27	21 16	12 55	14 06	15 22	16 42
S 50	20 12	20 55	21 59	13 03	14 20	15 42	17 07
52	20 22	21 10	22 24	13 06	14 26	15 51	17 19
54	20 34	21 27	23 03	13 10	14 33	16 01	17 33
56	20 48	21 48	////	13 15	14 40	16 13	17 49
58	21 04	22 16	////	13 20	14 49	16 26	18 08
S 60	21 23	22 58	////	13 25	14 59	16 42	18 33

Day	SUN Eqn. of Time 00ʰ	SUN Eqn. of Time 12ʰ	SUN Mer. Pass.	MOON Mer. Pass. Upper	MOON Mer. Pass. Lower	Age	Phase
	m s	m s	h m	h m	h m	d	
1	03 16	03 30	12 04	06 05	18 27	23	
2	03 45	03 59	12 04	06 50	19 13	24	
3	04 13	04 27	12 04	07 38	20 05	25	

Appendix F-3

CONVERSION OF ARC TO TIME

0°–59°		60°–119°		120°–179°		180°–239°		240°–299°		300°–359°			0′·00	0′·25	0′·50	0′·75
°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	′	m s	m s	m s	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00	0 01	0 02	0 03
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04	0 05	0 06	0 07
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08	0 09	0 10	0 11
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12	0 13	0 14	0 15
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16	0 17	0 18	0 19
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20	0 21	0 22	0 23
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24	0 25	0 26	0 27
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28	0 29	0 30	0 31
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32	0 33	0 34	0 35
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36	0 37	0 38	0 39
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40	0 41	0 42	0 43
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44	0 45	0 46	0 47
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48	0 49	0 50	0 51
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52	0 53	0 54	0 55
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56	0 57	0 58	0 59
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00	1 01	1 02	1 03
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04	1 05	1 06	1 07
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08	1 09	1 10	1 11
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12	1 13	1 14	1 15
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16	1 17	1 18	1 19
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20	1 21	1 22	1 23
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24	1 25	1 26	1 27
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28	1 29	1 30	1 31
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32	1 33	1 34	1 35
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36	1 37	1 38	1 39
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40	1 41	1 42	1 43
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44	1 45	1 46	1 47
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48	1 49	1 50	1 51
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52	1 53	1 54	1 55
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56	1 57	1 58	1 59
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00	2 01	2 02	2 03
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04	2 05	2 06	2 07
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08	2 09	2 10	2 11
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12	2 13	2 14	2 15
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16	2 17	2 18	2 19
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20	2 21	2 22	2 23
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24	2 25	2 26	2 27
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28	2 29	2 30	2 31
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32	2 33	2 34	2 35
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36	2 37	2 38	2 39
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40	2 41	2 42	2 43
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44	2 45	2 46	2 47
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48	2 49	2 50	2 51
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52	2 53	2 54	2 55
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56	2 57	2 58	2 59
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00	3 01	3 02	3 03
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04	3 05	3 06	3 07
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08	3 09	3 10	3 11
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12	3 13	3 14	3 15
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16	3 17	3 18	3 19
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20	3 21	3 22	3 23
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24	3 25	3 26	3 27
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28	3 29	3 30	3 31
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32	3 33	3 34	3 35
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36	3 37	3 38	3 39
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40	3 41	3 42	3 43
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44	3 45	3 46	3 47
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48	3 49	3 50	3 51
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52	3 53	3 54	3 55
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56	3 57	3 58	3 59

The above table is for converting expressions in arc to their equivalent in time ; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added* if *west*, *subtracted* if *east*) to give G.M.T. or vice versa, particularly in the case of sunrise, sunset, etc.

Appendix F-4

ALTITUDE CORRECTION TABLES 10°-90°—SUN, STARS, PLANETS

SUN

OCT.—MAR.

App. Alt.	Lower Limb	Upper Limb
9 34	+10·8	−21·5
9 45	+10·9	−21·4
9 56	+11·0	−21·3
10 08	+11·1	−21·2
10 21	+11·2	−21·1
10 34	+11·3	−21·0
10 47	+11·4	−20·9
11 01	+11·5	−20·8
11 15	+11·6	−20·7
11 30	+11·7	−20·6
11 46	+11·8	−20·5
12 02	+11·9	−20·4
12 19	+12·0	−20·3
12 37	+12·1	−20·2
12 55	+12·2	−20·1
13 14	+12·3	−20·0
13 35	+12·4	−19·9
13 56	+12·5	−19·8
14 18	+12·6	−19·7
14 42	+12·7	−19·6
15 06	+12·8	−19·5
15 32	+12·9	−19·4
15 59	+13·0	−19·3
16 28	+13·1	−19·2
16 59	+13·2	−19·1
17 32	+13·3	−19·0
18 06	+13·4	−18·9
18 42	+13·5	−18·8
19 21	+13·6	−18·7
20 03	+13·7	−18·6
20 48	+13·8	−18·5
21 35	+13·9	−18·4
22 26	+14·0	−18·3
23 22	+14·1	−18·2
24 21	+14·2	−18·1
25 26	+14·3	−18·0
26 36	+14·4	−17·9
27 52	+14·5	−17·8
29 15	+14·6	−17·7
30 46	+14·7	−17·6
32 26	+14·8	−17·5
34 17	+14·9	−17·4
36 20	+15·0	−17·3
38 36	+15·1	−17·2
41 08	+15·2	−17·1
43 59	+15·3	−17·0
47 10	+15·4	−16·9
50 46	+15·5	−16·8
54 49	+15·6	−16·7
59 23	+15·7	−16·6
64 30	+15·8	−16·5
70 12	+15·9	−16·4
76 26	+16·0	−16·3
83 05	+16·1	−16·2
90 00		

APR.—SEPT.

App. Alt.	Lower Limb	Upper Limb
9 39	+10·6	−21·2
9 51	+10·7	−21·1
10 03	+10·8	−21·0
10 15	+10·9	−20·9
10 27	+11·0	−20·8
10 40	+11·1	−20·7
10 54	+11·2	−20·6
11 08	+11·3	−20·5
11 23	+11·4	−20·4
11 38	+11·5	−20·3
11 54	+11·6	−20·2
12 10	+11·7	−20·1
12 28	+11·8	−20·0
12 46	+11·9	−19·9
13 05	+12·0	−19·8
13 24	+12·1	−19·7
13 45	+12·2	−19·6
14 07	+12·3	−19·5
14 30	+12·4	−19·4
14 54	+12·5	−19·3
15 19	+12·6	−19·2
15 46	+12·7	−19·1
16 14	+12·8	−19·0
16 44	+12·9	−18·9
17 15	+13·0	−18·8
17 48	+13·1	−18·7
18 24	+13·2	−18·6
19 01	+13·3	−18·5
19 42	+13·4	−18·4
20 25	+13·5	−18·3
21 11	+13·6	−18·2
22 00	+13·7	−18·1
22 54	+13·8	−18·0
23 51	+13·9	−17·9
24 53	+14·0	−17·8
26 00	+14·1	−17·7
27 13	+14·2	−17·6
28 33	+14·3	−17·5
30 00	+14·4	−17·4
31 35	+14·5	−17·3
33 20	+14·6	−17·2
35 17	+14·7	−17·1
37 26	+14·8	−17·0
39 50	+14·9	−16·9
42 31	+15·0	−16·8
45 31	+15·1	−16·7
48 55	+15·2	−16·6
52 44	+15·3	−16·5
57 02	+15·4	−16·4
61 51	+15·5	−16·3
67 17	+15·6	−16·2
73 16	+15·7	−16·1
79 43	+15·8	−16·0
86 32	+15·9	−15·9
90 00		

STARS AND PLANETS

App. Alt.	Corrn
9 56	−5·3
10 08	−5·2
10 20	−5·1
10 33	−5·0
10 46	−4·9
11 00	−4·8
11 14	−4·7
11 29	−4·6
11 45	−4·5
12 01	−4·4
12 18	−4·3
12 35	−4·2
12 54	−4·1
13 13	−4·0
13 33	−3·9
13 54	−3·8
14 16	−3·7
14 40	−3·6
15 04	−3·5
15 30	−3·4
15 57	−3·3
16 26	−3·2
16 56	−3·1
17 28	−3·0
18 02	−2·9
18 38	−2·8
19 17	−2·7
19 58	−2·6
20 42	−2·5
21 28	−2·4
22 19	−2·3
23 13	−2·2
24 11	−2·1
25 14	−2·0
26 22	−1·9
27 36	−1·8
28 56	−1·7
30 24	−1·6
32 00	−1·5
33 45	−1·4
35 40	−1·3
37 48	−1·2
40 08	−1·1
42 44	−1·0
45 36	−0·9
48 47	−0·8
52 18	−0·7
56 11	−0·6
60 28	−0·5
65 08	−0·4
70 11	−0·3
75 34	−0·2
81 13	−0·1
87 03	0·0
90 00	

App. Alt.	Additional Corrn
1970	
VENUS	
Jan. 1-July 22	
0	+0·1
42	
July 23-Sept. 5	
0	+0·2
47	
Sept. 6-Oct. 1	
0	+0·3
46	
Oct. 2-Oct. 16	
0	+0·4
11	+0·5
41	
Oct. 17-Oct. 24	
0	+0·5
6	+0·6
20	+0·7
31	
Oct. 25-Nov. 28	
0	+0·6
4	+0·7
12	+0·8
22	
Nov. 29-Dec. 6	
0	+0·5
6	+0·6
20	+0·7
31	
Dec. 7-Dec. 21	
0	+0·4
11	+0·5
41	
Dec. 22-Dec. 31	
0	+0·3
46	
MARS	
Jan. 1-Dec. 31	
0	+0·1
60	

DIP

Ht. of Eye (ft.)	Corrn	Ht. of Eye (ft.)	Corrn
1·1	−1·1	44	−6·5
1·4	−1·2	45	−6·6
1·6	−1·3	47	−6·7
1·9	−1·4	48	−6·8
2·2	−1·5	49	−6·9
2·5	−1·6	51	−7·0
2·8	−1·7	52	−7·1
3·2	−1·8	54	−7·2
3·6	−1·9	55	−7·3
4·0	−2·0	57	−7·4
4·4	−2·1	58	−7·5
4·9	−2·2	60	−7·6
5·3	−2·3	62	−7·7
5·8	−2·4	63	−7·8
6·3	−2·5	65	−7·9
6·9	−2·6	67	−8·0
7·4	−2·7	68	−8·1
8·0	−2·8	70	−8·2
8·6	−2·9	72	−8·3
9·2	−3·0	74	−8·4
9·8	−3·1	75	−8·5
10·5	−3·2	77	−8·6
11·2	−3·3	79	−8·7
11·9	−3·4	81	−8·8
12·6	−3·5	83	−8·9
13·3	−3·6	85	−9·0
14·1	−3·7	87	−9·1
14·9	−3·8	88	−9·2
15·7	−3·9	90	−9·3
16·5	−4·0	92	−9·4
17·4	−4·1	94	−9·5
18·3	−4·2	96	−9·6
19·1	−4·3	98	−9·7
20·1	−4·4	101	−9·8
21·0	−4·5	103	−9·9
22·0	−4·6	105	−10·0
22·9	−4·7	107	−10·1
23·9	−4·8	109	−10·2
24·9	−4·9	111	−10·3
26·0	−5·0	113	−10·4
27·1	−5·1	116	−10·5
28·1	−5·2	118	−10·6
29·2	−5·3	120	−10·7
30·4	−5·4	122	−10·8
31·5	−5·5	125	−10·9
32·7	−5·6	127	−11·0
33·9	−5·7	129	−11·1
35·1	−5·8	132	−11·2
36·3	−5·9	134	−11·3
37·6	−6·0	136	−11·4
38·9	−6·1	139	−11·5
40·1	−6·2	141	−11·6
41·5	−6·3	144	−11·7
42·8	−6·4	146	−11·8
44·2		149	

App. Alt. = Apparent altitude = Sextant altitude corrected for index error and dip.

For daylight observations of Venus, see page 260.

242-578 O - 69

Appendix F-5

ALTITUDE CORRECTION TABLES 0°–10°—SUN, STARS, PLANETS A3

App. Alt.	OCT.–MAR. SUN Lower Limb	OCT.–MAR. SUN Upper Limb	APR.–SEPT. SUN Lower Limb	APR.–SEPT. SUN Upper Limb	STARS PLANETS
° ′	′	′	′	′	′
0 00	−18.2	−50.5	−18.4	−50.2	−34.5
03	17.5	49.8	17.8	49.6	33.8
06	16.9	49.2	17.1	48.9	33.2
09	16.3	48.6	16.5	48.3	32.6
12	15.7	48.0	15.9	47.7	32.0
15	15.1	47.4	15.3	47.1	31.4
0 18	−14.5	−46.8	−14.8	−46.6	−30.8
21	14.0	46.3	14.2	46.0	30.3
24	13.5	45.8	13.7	45.5	29.8
27	12.9	45.2	13.2	45.0	29.2
30	12.4	44.7	12.7	44.5	28.7
33	11.9	44.2	12.2	44.0	28.2
0 36	−11.5	−43.8	−11.7	−43.5	−27.8
39	11.0	43.3	11.2	43.0	27.3
42	10.5	42.8	10.8	42.6	26.8
45	10.1	42.4	10.3	42.1	26.4
48	9.6	41.9	9.9	41.7	25.9
51	9.2	41.5	9.5	41.3	25.5
0 54	− 8.8	−41.1	− 9.1	−40.9	−25.1
0 57	8.4	40.7	8.7	40.5	24.7
1 00	8.0	40.3	8.3	40.1	24.3
03	7.7	40.0	7.9	39.7	24.0
06	7.3	39.6	7.5	39.3	23.6
09	6.9	39.2	7.2	39.0	23.2
1 12	− 6.6	−38.9	− 6.8	−38.6	−22.9
15	6.2	38.5	6.5	38.3	22.5
18	5.9	38.2	6.2	38.0	22.2
21	5.6	37.9	5.8	37.6	21.9
24	5.3	37.6	5.5	37.3	21.6
27	4.9	37.2	5.2	37.0	21.2
1 30	− 4.6	−36.9	− 4.9	−36.7	−20.9
35	4.2	36.5	4.4	36.2	20.5
40	3.7	36.0	4.0	35.8	20.0
45	3.2	35.5	3.5	35.3	19.5
50	2.8	35.1	3.1	34.9	19.1
1 55	2.4	34.7	2.6	34.4	18.7
2 00	− 2.0	−34.3	− 2.2	−34.0	−18.3
05	1.6	33.9	1.8	33.6	17.9
10	1.2	33.5	1.5	33.3	17.5
15	0.9	33.2	1.1	32.9	17.2
20	0.5	32.8	0.8	32.6	16.8
25	− 0.2	32.5	0.4	32.2	16.5
2 30	+ 0.2	−32.1	− 0.1	−31.9	−16.1
35	0.5	31.8	+ 0.2	31.6	15.8
40	0.8	31.5	0.5	31.3	15.5
45	1.1	31.2	0.8	31.0	15.2
50	1.4	30.9	1.1	30.7	14.9
2 55	1.6	30.7	1.4	30.4	14.7
3 00	+ 1.9	−30.4	+ 1.7	−30.1	−14.4
05	2.2	30.1	1.9	29.9	14.1
10	2.4	29.9	2.1	29.7	13.9
15	2.6	29.7	2.4	29.4	13.7
20	2.9	29.4	2.6	29.2	13.4
25	3.1	29.2	2.9	28.9	13.2
3 30	+ 3.3	−29.0	+ 3.1	−28.7	−13.0

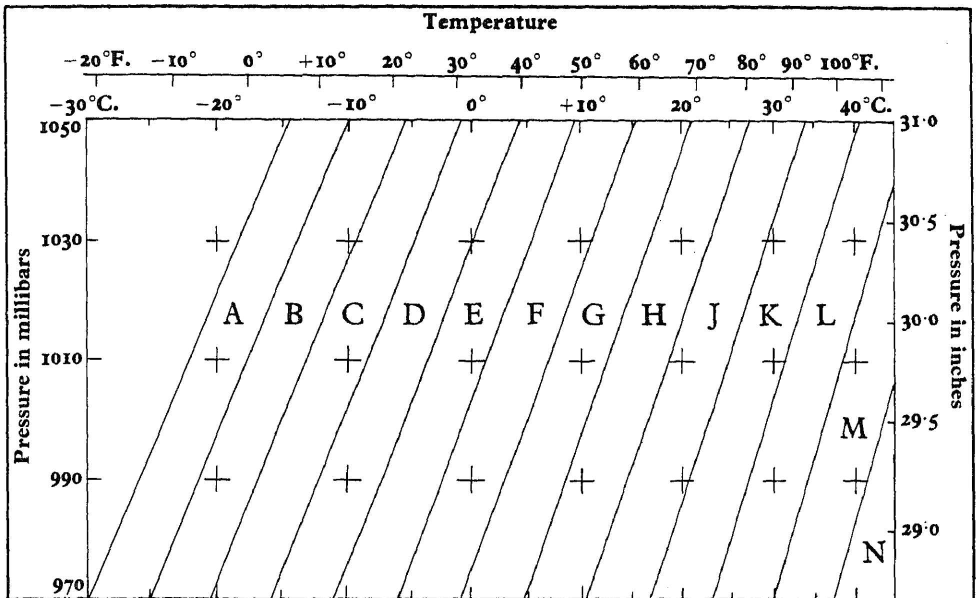
App. Alt.	OCT.–MAR. SUN Lower Limb	OCT.–MAR. SUN Upper Limb	APR.–SEPT. SUN Lower Limb	APR.–SEPT. SUN Upper Limb	STARS PLANETS
° ′	′	′	′	′	′
3 30	+ 3.3	−29.0	+ 3.1	−28.7	−13.0
35	3.6	28.7	3.3	28.5	12.7
40	3.8	28.5	3.5	28.3	12.5
45	4.0	28.3	3.7	28.1	12.3
50	4.2	28.1	3.9	27.9	12.1
3 55	4.4	27.9	4.1	27.7	11.9
4 00	+ 4.5	−27.8	+ 4.3	−27.5	−11.8
05	4.7	27.6	4.5	27.3	11.6
10	4.9	27.4	4.6	27.2	11.4
15	5.1	27.2	4.8	27.0	11.2
20	5.2	27.1	5.0	26.8	11.1
25	5.4	26.9	5.1	26.7	10.9
4 30	+ 5.6	−26.7	+ 5.3	−26.5	−10.7
35	5.7	26.6	5.5	26.3	10.6
40	5.9	26.4	5.6	26.2	10.4
45	6.0	26.3	5.8	26.0	10.3
50	6.2	26.1	5.9	25.9	10.1
4 55	6.3	26.0	6.0	25.8	10.0
5 00	+ 6.4	−25.9	+ 6.2	−25.6	− 9.9
05	6.6	25.7	6.3	25.5	9.7
10	6.7	25.6	6.4	25.4	9.6
15	6.8	25.5	6.6	25.2	9.5
20	6.9	25.4	6.7	25.1	9.4
25	7.1	25.2	6.8	25.0	9.2
5 30	+ 7.2	−25.1	+ 6.9	−24.9	− 9.1
35	7.3	25.0	7.0	24.8	9.0
40	7.4	24.9	7.2	24.6	8.9
45	7.5	24.8	7.3	24.5	8.8
50	7.6	24.7	7.4	24.4	8.7
5 55	7.7	24.6	7.5	24.3	8.6
6 00	+ 7.8	−24.5	+ 7.6	−24.2	− 8.5
10	8.0	24.3	7.8	24.0	8.3
20	8.2	24.1	8.0	23.8	8.1
30	8.4	23.9	8.1	23.7	7.9
40	8.6	23.7	8.3	23.5	7.7
6 50	8.7	23.6	8.5	23.3	7.6
7 00	+ 8.9	−23.4	+ 8.6	−23.2	− 7.4
10	9.1	23.2	8.8	23.0	7.2
20	9.2	23.1	9.0	22.8	7.1
30	9.3	23.0	9.1	22.7	7.0
40	9.5	22.8	9.2	22.6	6.8
7 50	9.6	22.7	9.4	22.4	6.7
8 00	+ 9.7	−22.6	+ 9.5	−22.3	− 6.6
10	9.9	22.4	9.6	22.2	6.4
20	10.0	22.3	9.7	22.1	6.3
30	10.1	22.2	9.8	22.0	6.2
40	10.2	22.1	10.0	21.8	6.1
8 50	10.3	22.0	10.1	21.7	6.0
9 00	+10.4	−21.9	+10.2	−21.6	− 5.9
10	10.5	21.8	10.3	21.5	5.8
20	10.6	21.7	10.4	21.4	5.7
30	10.7	21.6	10.5	21.3	5.6
40	10.8	21.5	10.6	21.2	5.5
9 50	10.9	21.4	10.6	21.2	5.4
10 00	+11.0	−21.3	+10.7	−21.1	− 5.3

Additional corrections for temperature and pressure are given on the following page.
For bubble sextant observations ignore dip and use the star corrections for Sun, planets, and stars.

Appendix F-6

ALTITUDE CORRECTION TABLES—ADDITIONAL CORRECTIONS

ADDITIONAL REFRACTION CORRECTIONS FOR NON-STANDARD CONDITIONS



App. Alt.	A	B	C	D	E	F	G	H	J	K	L	M	N	App. Alt.
° ′	′	′	′	′	′	′	′	′	′	′	′	′	′	° ′
0 00	−6·9	−5·7	−4·6	−3·4	−2·3	−1·1	0·0	+1·1	+2·3	+3·4	+4·6	+5·7	+6·9	0 00
0 30	5·2	4·4	3·5	2·6	1·7	0·9	0·0	0·9	1·7	2·6	3·5	4·4	5·2	0 30
1 00	4·3	3·5	2·8	2·1	1·4	0·7	0·0	0·7	1·4	2·1	2·8	3·5	4·3	1 00
1 30	3·5	2·9	2·4	1·8	1·2	0·6	0·0	0·6	1·2	1·8	2·4	2·9	3·5	1 30
2 00	3·0	2·5	2·0	1·5	1·0	0·5	0·0	0·5	1·0	1·5	2·0	2·5	3·0	2 00
2 30	−2·5	−2·1	−1·6	−1·2	−0·8	−0·4	0·0	+0·4	+0·8	+1·2	+1·6	+2·1	+2·5	2 30
3 00	2·2	1·8	1·5	1·1	0·7	0·4	0·0	0·4	0·7	1·1	1·5	1·8	2·2	3 00
3 30	2·0	1·6	1·3	1·0	0·7	0·3	0·0	0·3	0·7	1·0	1·3	1·6	2·0	3 30
4 00	1·8	1·5	1·2	0·9	0·6	0·3	0·0	0·3	0·6	0·9	1·2	1·5	1·8	4 00
4 30	1·6	1·4	1·1	0·8	0·5	0·3	0·0	0·3	0·5	0·8	1·1	1·4	1·6	4 30
5 00	−1·5	−1·3	−1·0	−0·8	−0·5	−0·2	0·0	+0·2	+0·5	+0·8	+1·0	+1·3	+1·5	5 00
6	1·3	1·1	0·9	0·6	0·4	0·2	0·0	0·2	0·4	0·6	0·9	1·1	1·3	6
7	1·1	0·9	0·7	0·6	0·4	0·2	0·0	0·2	0·4	0·6	0·7	0·9	1·1	7
8	1·0	0·8	0·7	0·5	0·3	0·2	0·0	0·2	0·3	0·5	0·7	0·8	1·0	8
9	0·9	0·7	0·6	0·4	0·3	0·1	0·0	0·1	0·3	0·4	0·6	0·7	0·9	9
10 00	−0·8	−0·7	−0·5	−0·4	−0·3	−0·1	0·0	+0·1	+0·3	+0·4	+0·5	+0·7	+0·8	10 00
12	0·7	0·6	0·5	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·5	0·6	0·7	12
14	0·6	0·5	0·4	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·4	0·5	0·6	14
16	0·5	0·4	0·3	0·3	0·2	0·1	0·0	0·1	0·2	0·3	0·3	0·4	0·5	16
18	0·4	0·4	0·3	0·2	0·2	0·1	0·0	0·1	0·2	0·2	0·3	0·4	0·4	18
20 00	−0·4	−0·3	−0·3	−0·2	−0·1	−0·1	0·0	+0·1	+0·1	+0·2	+0·3	+0·3	+0·4	20 00
25	0·3	0·3	0·2	0·2	0·1	−0·1	0·0	+0·1	0·1	0·2	0·2	0·3	0·3	25
30	0·3	0·2	0·2	0·1	0·1	0·0	0·0	0·0	0·1	0·1	0·2	0·2	0·3	30
35	0·2	0·2	0·1	0·1	0·1	0·0	0·0	0·0	0·1	0·1	0·1	0·2	0·2	35
40	0·2	0·1	0·1	0·1	−0·1	0·0	0·0	0·0	+0·1	0·1	0·1	0·1	0·2	40
50 00	−0·1	−0·1	−0·1	−0·1	0·0	0·0	0·0	0·0	0·0	+0·1	+0·1	+0·1	+0·1	50 00

The graph is entered with arguments temperature and pressure to find a zone letter; using as arguments this zone letter and apparent altitude (sextant altitude corrected for dip), a correction is taken from the table. This correction is to be applied to the sextant altitude in addition to the corrections for standard conditions (for the Sun, planets and stars from the inside front cover and for the Moon from the inside back cover).

Appendix F-7

ALTITUDE CORRECTION TABLES 0°–35°—MOON

App. Alt.	0°–4° Corrⁿ	5°–9° Corrⁿ	10°–14° Corrⁿ	15°–19° Corrⁿ	20°–24° Corrⁿ	25°–29° Corrⁿ	30°–34° Corrⁿ	App. Alt.
′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	′
00	0 33·8	5 58·2	10 62·1	15 62·8	20 62·2	25 60·8	30 58·9	00
10	35·9	58·5	62·2	62·8	62·1	60·8	58·8	10
20	37·8	58·7	62·2	62·8	62·1	60·7	58·8	20
30	39·6	58·9	62·3	62·8	62·1	60·7	58·7	30
40	41·2	59·1	62·3	62·8	62·0	60·6	58·6	40
50	42·6	59·3	62·4	62·7	62·0	60·6	58·5	50
00	1 44·0	6 59·5	11 62·4	16 62·7	21 62·0	26 60·5	31 58·5	00
10	45·2	59·7	62·4	62·7	61·9	60·4	58·4	10
20	46·3	59·9	62·5	62·7	61·9	60·4	58·3	20
30	47·3	60·0	62·5	62·7	61·9	60·3	58·2	30
40	48·3	60·2	62·5	62·7	61·8	60·3	58·2	40
50	49·2	60·3	62·6	62·7	61·8	60·2	58·1	50
00	2 50·0	7 60·5	12 62·6	17 62·7	22 61·7	27 60·1	32 58·0	00
10	50·8	60·6	62·6	62·6	61·7	60·1	57·9	10
20	51·4	60·7	62·6	62·6	61·6	60·0	57·8	20
30	52·1	60·9	62·7	62·6	61·6	59·9	57·8	30
40	52·7	61·0	62·7	62·6	61·5	59·9	57·7	40
50	53·3	61·1	62·7	62·6	61·5	59·8	57·6	50
00	3 53·8	8 61·2	13 62·7	18 62·5	23 61·5	28 59·7	33 57·5	00
10	54·3	61·3	62·7	62·5	61·4	59·7	57·4	10
20	54·8	61·4	62·7	62·5	61·4	59·6	57·4	20
30	55·2	61·5	62·8	62·5	61·3	59·6	57·3	30
40	55·6	61·6	62·8	62·4	61·3	59·5	57·2	40
50	56·0	61·6	62·8	62·4	61·2	59·4	57·1	50
00	4 56·4	9 61·7	14 62·8	19 62·4	24 61·2	29 59·3	34 57·0	00
10	56·7	61·8	62·8	62·3	61·1	59·3	56·9	10
20	57·1	61·9	62·8	62·3	61·1	59·2	56·9	20
30	57·4	61·9	62·8	62·3	61·0	59·1	56·8	30
40	57·7	62·0	62·8	62·2	60·9	59·1	56·7	40
50	57·9	62·1	62·8	62·2	60·9	59·0	56·6	50

H.P.	L U	L U	L U	L U	L U	L U	L U	H.P.
′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′
54·0	0·3 0·9	0·3 0·9	0·4 1·0	0·5 1·1	0·6 1·2	0·7 1·3	0·9 1·5	54·0
54·3	0·7 1·1	0·7 1·2	0·7 1·2	0·8 1·3	0·9 1·4	1·1 1·5	1·2 1·7	54·3
54·6	1·1 1·4	1·1 1·4	1·1 1·4	1·2 1·5	1·3 1·6	1·4 1·7	1·5 1·8	54·6
54·9	1·4 1·6	1·5 1·6	1·5 1·6	1·6 1·7	1·6 1·8	1·8 1·9	1·9 2·0	54·9
55·2	1·8 1·8	1·8 1·8	1·9 1·9	1·9 1·9	2·0 2·0	2·1 2·1	2·2 2·2	55·2
55·5	2·2 2·0	2·2 2·0	2·3 2·1	2·3 2·1	2·4 2·2	2·4 2·3	2·5 2·4	55·5
55·8	2·6 2·2	2·6 2·2	2·6 2·3	2·7 2·3	2·7 2·4	2·8 2·4	2·9 2·5	55·8
56·1	3·0 2·4	3·0 2·5	3·0 2·5	3·0 2·5	3·1 2·6	3·1 2·6	3·2 2·7	56·1
56·4	3·4 2·7	3·4 2·7	3·4 2·7	3·4 2·7	3·4 2·8	3·5 2·8	3·5 2·9	56·4
56·7	3·7 2·9	3·7 2·9	3·8 2·9	3·8 2·9	3·8 3·0	3·8 3·0	3·9 3·0	56·7
57·0	4·1 3·1	4·1 3·1	4·1 3·1	4·1 3·1	4·2 3·1	4·2 3·2	4·2 3·2	57·0
57·3	4·5 3·3	4·5 3·3	4·5 3·3	4·5 3·3	4·5 3·3	4·5 3·4	4·6 3·4	57·3
57·6	4·9 3·5	4·9 3·5	4·9 3·5	4·9 3·5	4·9 3·5	4·9 3·5	4·9 3·6	57·6
57·9	5·3 3·8	5·3 3·8	5·2 3·8	5·2 3·7	5·2 3·7	5·2 3·7	5·2 3·7	57·9
58·2	5·6 4·0	5·6 4·0	5·6 4·0	5·6 4·0	5·6 3·9	5·6 3·9	5·6 3·9	58·2
58·5	6·0 4·2	6·0 4·2	6·0 4·2	6·0 4·2	6·0 4·1	5·9 4·1	5·9 4·1	58·5
58·8	6·4 4·4	6·4 4·4	6·4 4·4	6·3 4·4	6·3 4·3	6·3 4·3	6·2 4·2	58·8
59·1	6·8 4·6	6·8 4·6	6·7 4·6	6·7 4·6	6·7 4·5	6·6 4·5	6·6 4·4	59·1
59·4	7·2 4·8	7·1 4·8	7·1 4·8	7·1 4·8	7·0 4·7	7·0 4·7	6·9 4·6	59·4
59·7	7·5 5·1	7·5 5·0	7·5 5·0	7·5 5·0	7·4 4·9	7·3 4·8	7·2 4·7	59·7
60·0	7·9 5·3	7·9 5·3	7·9 5·2	7·8 5·2	7·8 5·1	7·7 5·0	7·6 4·9	60·0
60·3	8·3 5·5	8·3 5·5	8·2 5·4	8·2 5·4	8·1 5·3	8·0 5·2	7·9 5·1	60·3
60·6	8·7 5·7	8·7 5·7	8·6 5·7	8·6 5·6	8·5 5·5	8·4 5·4	8·2 5·3	60·6
60·9	9·1 5·9	9·0 5·9	9·0 5·9	8·9 5·8	8·8 5·7	8·7 5·6	8·6 5·4	60·9
61·2	9·5 6·2	9·4 6·1	9·4 6·1	9·3 6·0	9·2 5·9	9·1 5·8	8·9 5·6	61·2
61·5	9·8 6·4	9·8 6·3	9·7 6·3	9·7 6·2	9·5 6·1	9·4 5·9	9·2 5·8	61·5

DIP

Ht. of Eye	Corrⁿ	Ht. of Eye	Corrⁿ	Ht. of Eye	Corrⁿ
ft.	′	ft.	′	ft.	′
4·0	−2·0	24	−4·9	63	− 7·8
4·4	−2·1	26	−5·0	65	− 7·9
4·9	−2·2	27	−5·1	67	− 8·0
5·3	−2·3	28	−5·2	68	− 8·1
5·8	−2·4	29	−5·3	70	− 8·2
6·3	−2·5	30	−5·4	72	− 8·3
6·9	−2·6	31	−5·5	74	− 8·4
7·4	−2·7	32	−5·6	75	− 8·5
8·0	−2·8	33	−5·7	77	− 8·6
8·6	−2·9	35	−5·8	79	− 8·7
9·2	−3·0	36	−5·9	81	− 8·8
9·8	−3·1	37	−6·0	83	− 8·9
10·5	−3·2	38	−6·1	85	− 9·0
11·2	−3·3	40	−6·2	87	− 9·1
11·9	−3·4	41	−6·3	88	− 9·2
12·6	−3·5	42	−6·4	90	− 9·3
13·3	−3·6	44	−6·5	92	− 9·4
14·1	−3·7	45	−6·6	94	− 9·5
14·9	−3·8	47	−6·7	96	− 9·6
15·7	−3·9	48	−6·8	98	− 9·7
16·5	−4·0	49	−6·9	101	− 9·8
17·4	−4·1	51	−7·0	103	− 9·9
18·3	−4·2	52	−7·1	105	−10·0
19·1	−4·3	54	−7·2	107	−10·1
20·1	−4·4	55	−7·3	109	−10·2
21·0	−4·5	57	−7·4	111	−10·3
22·0	−4·6	58	−7·5	113	−10·4
22·9	−4·7	60	−7·6	116	−10·5
23·9	−4·8	62	−7·7	118	−10·6
24·9		63		120	

MOON CORRECTION TABLE

The correction is in two parts; the first correction is taken from the upper part of the table with argument apparent altitude, and the second from the lower part, with argument H.P., in the same column as that from which the first correction was taken. Separate corrections are given in the lower part for lower (L) and upper (U) limbs. All corrections are to be **added** to apparent altitude, *but 30′ is to be subtracted from the altitude of the upper limb.*

For corrections for pressure and temperature see page A4.

For bubble sextant observations ignore dip, take the mean of upper and lower limb corrections and subtract 15′ from the altitude.

App. Alt. = Apparent altitude = Sextant altitude corrected for index error and dip.

Appendix F-8

ALTITUDE CORRECTION TABLES 35°-90°—MOON

App. Alt.	35°–39°	40°–44°	45°–49°	50°–54°	55°–59°	60°–64°	65°–69°	70°–74°	75°–79°	80°–84°	85°–89°	App. Alt.
	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	
′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	′
00	35 56·5	40 53·7	45 50·5	50 46·9	55 43·1	60 38·9	65 34·6	70 30·1	75 25·3	80 20·5	85 15·6	00
10	56·4	53·6	50·4	46·8	42·9	38·8	34·4	29·9	25·2	20·4	15·5	10
20	56·3	53·5	50·2	46·7	42·8	38·7	34·3	29·7	25·0	20·2	15·3	20
30	56·2	53·4	50·1	46·5	42·7	38·5	34·1	29·6	24·9	20·0	15·1	30
40	56·2	53·3	50·0	46·4	42·5	38·4	34·0	29·4	24·7	19·9	15·0	40
50	56·1	53·2	49·9	46·3	42·4	38·2	33·8	29·3	24·5	19·7	14·8	50
00	36 56·0	41 53·1	46 49·8	51 46·2	56 42·3	61 38·1	66 33·7	71 29·1	76 24·4	81 19·6	86 14·6	00
10	55·9	53·0	49·7	46·0	42·1	37·9	33·5	29·0	24·2	19·4	14·5	10
20	55·8	52·8	49·5	45·9	42·0	37·8	33·4	28·8	24·1	19·2	14·3	20
30	55·7	52·7	49·4	45·8	41·8	37·7	33·2	28·7	23·9	19·1	14·1	30
40	55·6	52·6	49·3	45·7	41·7	37·5	33·1	28·5	23·8	18·9	14·0	40
50	55·5	52·5	49·2	45·5	41·6	37·4	32·9	28·3	23·6	18·7	13·8	50
00	37 55·4	42 52·4	47 49·1	52 45·4	57 41·4	62 37·2	67 32·8	72 28·2	77 23·4	82 18·6	87 13·7	00
10	55·3	52·3	49·0	45·3	41·3	37·1	32·6	28·0	23·3	18·4	13·5	10
20	55·2	52·2	48·8	45·2	41·2	36·9	32·5	27·9	23·1	18·2	13·3	20
30	55·1	52·1	48·7	45·0	41·0	36·8	32·3	27·7	22·9	18·1	13·2	30
40	55·0	52·0	48·6	44·9	40·9	36·6	32·2	27·6	22·8	17·9	13·0	40
50	55·0	51·9	48·5	44·8	40·8	36·5	32·0	27·4	22·6	17·8	12·8	50
00	38 54·9	43 51·8	48 48·4	53 44·6	58 40·6	63 36·4	68 31·9	73 27·2	78 22·5	83 17·6	88 12·7	00
10	54·8	51·7	48·2	44·5	40·5	36·2	31·7	27·1	22·3	17·4	12·5	10
20	54·7	51·6	48·1	44·4	40·3	36·1	31·6	26·9	22·1	17·3	12·3	20
30	54·6	51·5	48·0	44·2	40·2	35·9	31·4	26·8	22·0	17·1	12·2	30
40	54·5	51·4	47·9	44·1	40·1	35·8	31·3	26·6	21·8	16·9	12·0	40
50	54·4	51·2	47·8	44·0	39·9	35·6	31·1	26·5	21·7	16·8	11·8	50
00	39 54·3	44 51·1	49 47·6	54 43·9	59 39·8	64 35·5	69 31·0	74 26·3	79 21·5	84 16·6	89 11·7	00
10	54·2	51·0	47·5	43·7	39·6	35·3	30·8	26·1	21·3	16·5	11·5	10
20	54·1	50·9	47·4	43·6	39·5	35·2	30·7	26·0	21·2	16·3	11·4	20
30	54·0	50·8	47·3	43·5	39·4	35·0	30·5	25·8	21·0	16·1	11·2	30
40	53·9	50·7	47·2	43·3	39·2	34·9	30·4	25·7	20·9	16·0	11·0	40
50	53·8	50·6	47·0	43·2	39·1	34·7	30·2	25·5	20·7	15·8	10·9	50
H.P.	L U	L U	L U	L U	L U	L. U	L U	L U	L U	L U	L U	H.P.
′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′ ′	′
54·0	1·1 1·7	1·3 1·9	1·5 2·1	1·7 2·4	2·0 2·6	2·3 2·9	2·6 3·2	2·9 3·5	3·2 3·8	3·5 4·1	3·8 4·5	54·0
54·3	1·4 1·8	1·6 2·0	1·8 2·2	2·0 2·5	2·3 2·7	2·5 3·0	2·8 3·2	3·0 3·5	3·3 3·8	3·6 4·1	3·9 4·4	54·3
54·6	1·7 2·0	1·9 2·2	2·1 2·4	2·3 2·6	2·5 2·8	2·7 3·0	3·0 3·3	3·2 3·5	3·5 3·8	3·7 4·1	4·0 4·3	54·6
54·9	2·0 2·2	2·2 2·3	2·3 2·5	2·5 2·7	2·7 2·9	2·9 3·1	3·2 3·3	3·4 3·5	3·6 3·8	3·9 4·0	4·1 4·3	54·9
55·2	2·3 2·3	2·5 2·4	2·6 2·6	2·8 2·8	3·0 2·9	3·2 3·1	3·4 3·3	3·6 3·5	3·8 3·7	4·0 4·0	4·2 4·2	55·2
55·5	2·7 2·5	2·8 2·6	2·9 2·7	3·1 2·9	3·2 3·0	3·4 3·2	3·6 3·4	3·7 3·5	3·9 3·7	4·1 3·9	4·3 4·1	55·5
55·8	3·0 2·6	3·1 2·7	3·2 2·8	3·3 3·0	3·5 3·1	3·6 3·3	3·8 3·4	3·9 3·6	4·1 3·7	4·2 3·9	4·4 4·0	55·8
56·1	3·3 2·8	3·4 2·9	3·5 3·0	3·6 3·1	3·7 3·2	3·8 3·3	4·0 3·4	4·1 3·6	4·2 3·7	4·4 3·8	4·5 4·0	56·1
56·4	3·6 2·9	3·7 3·0	3·8 3·1	3·9 3·2	3·9 3·3	4·0 3·4	4·1 3·5	4·3 3·6	4·4 3·7	4·5 3·8	4·6 3·9	56·4
56·7	3·9 3·1	4·0 3·1	4·1 3·2	4·1 3·3	4·2 3·3	4·3 3·4	4·3 3·5	4·4 3·6	4·5 3·7	4·6 3·8	4·7 3·8	56·7
57·0	4·3 3·2	4·3 3·3	4·3 3·3	4·4 3·4	4·4 3·4	4·5 3·5	4·5 3·5	4·6 3·6	4·7 3·6	4·7 3·7	4·8 3·8	57·0
57·3	4·6 3·4	4·6 3·4	4·6 3·4	4·6 3·5	4·7 3·5	4·7 3·5	4·7 3·6	4·8 3·6	4·8 3·6	4·8 3·7	4·9 3·7	57·3
57·6	4·9 3·6	4·9 3·6	4·9 3·6	4·9 3·6	4·9 3·6	4·9 3·6	4·9 3·6	4·9 3·6	5·0 3·6	5·0 3·6	5·0 3·6	57·6
57·9	5·2 3·7	5·2 3·7	5·2 3·7	5·2 3·7	5·2 3·7	5·1 3·6	5·1 3·6	5·1 3·6	5·1 3·6	5·1 3·6	5·1 3·6	57·9
58·2	5·5 3·9	5·5 3·8	5·5 3·8	5·4 3·8	5·4 3·7	5·4 3·7	5·3 3·7	5·3 3·6	5·2 3·6	5·2 3·5	5·2 3·5	58·2
58·5	5·9 4·0	5·8 4·0	5·8 3·9	5·7 3·9	5·6 3·8	5·6 3·8	5·5 3·7	5·5 3·6	5·4 3·6	5·3 3·5	5·3 3·4	58·5
58·8	6·2 4·2	6·1 4·1	6·0 4·1	6·0 4·0	5·9 3·9	5·8 3·8	5·7 3·7	5·6 3·6	5·5 3·5	5·4 3·5	5·3 3·4	58·8
59·1	6·5 4·3	6·4 4·3	6·3 4·2	6·2 4·1	6·1 4·0	6·0 3·9	5·9 3·8	5·8 3·6	5·7 3·5	5·6 3·4	5·4 3·3	59·1
59·4	6·8 4·5	6·7 4·4	6·6 4·3	6·5 4·2	6·4 4·1	6·2 3·9	6·1 3·8	6·0 3·7	5·8 3·5	5·7 3·4	5·5 3·2	59·4
59·7	7·1 4·6	7·0 4·5	6·9 4·4	6·8 4·3	6·6 4·1	6·5 4·0	6·3 3·8	6·2 3·7	6·0 3·5	5·8 3·3	5·6 3·2	59·7
60·0	7·5 4·8	7·3 4·7	7·2 4·5	7·0 4·4	6·9 4·2	6·7 4·0	6·5 3·9	6·3 3·7	6·1 3·5	5·9 3·3	5·7 3·1	60·0
60·3	7·8 5·0	7·6 4·8	7·5 4·7	7·3 4·5	7·1 4·3	6·9 4·1	6·7 3·9	6·5 3·7	6·3 3·5	6·0 3·2	5·8 3·0	60·3
60·6	8·1 5·1	7·9 5·0	7·7 4·8	7·6 4·6	7·3 4·4	7·1 4·2	6·9 3·9	6·7 3·7	6·4 3·4	6·2 3·2	5·9 2·9	60·6
60·9	8·4 5·3	8·2 5·1	8·0 4·9	7·8 4·7	7·6 4·5	7·3 4·2	7·1 4·0	6·8 3·7	6·6 3·4	6·3 3·2	6·0 2·9	60·9
61·2	8·7 5·4	8·5 5·2	8·3 5·0	8·1 4·8	7·8 4·5	7·6 4·3	7·3 4·0	7·0 3·7	6·7 3·4	6·4 3·1	6·1 2·8	61·2
61·5	9·1 5·6	8·8 5·4	8·6 5·1	8·3 4·9	8·1 4·6	7·8 4·3	7·5 4·0	7·2 3·7	6·9 3·4	6·5 3·1	6·2 2·7	61·5

Appendix F-9

18ᵐ s	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
	° ′	° ′	° ′	′	′	′	′	′	′
00	4 30.0	4 30.7	4 17.7	0.0	0.0	6.0	1.9	12.0	3.7
01	4 30.3	4 31.0	4 17.9	0.1	0.0	6.1	1.9	12.1	3.7
02	4 30.5	4 31.2	4 18.2	0.2	0.1	6.2	1.9	12.2	3.8
03	4 30.8	4 31.5	4 18.4	0.3	0.1	6.3	1.9	12.3	3.8
04	4 31.0	4 31.7	4 18.7	0.4	0.1	6.4	2.0	12.4	3.8
05	4 31.3	4 32.0	4 18.9	0.5	0.2	6.5	2.0	12.5	3.9
06	4 31.5	4 32.2	4 19.1	0.6	0.2	6.6	2.0	12.6	3.9
07	4 31.8	4 32.5	4 19.4	0.7	0.2	6.7	2.1	12.7	3.9
08	4 32.0	4 32.7	4 19.6	0.8	0.2	6.8	2.1	12.8	3.9
09	4 32.3	4 33.0	4 19.8	0.9	0.3	6.9	2.1	12.9	4.0
10	4 32.5	4 33.2	4 20.1	1.0	0.3	7.0	2.2	13.0	4.0
11	4 32.8	4 33.5	4 20.3	1.1	0.3	7.1	2.2	13.1	4.0
12	4 33.0	4 33.7	4 20.6	1.2	0.4	7.2	2.2	13.2	4.1
13	4 33.3	4 34.0	4 20.8	1.3	0.4	7.3	2.3	13.3	4.1
14	4 33.5	4 34.2	4 21.0	1.4	0.4	7.4	2.3	13.4	4.1
15	4 33.8	4 34.5	4 21.3	1.5	0.5	7.5	2.3	13.5	4.2
16	4 34.0	4 34.8	4 21.5	1.6	0.5	7.6	2.3	13.6	4.2
17	4 34.3	4 35.0	4 21.8	1.7	0.5	7.7	2.4	13.7	4.2
18	4 34.5	4 35.3	4 22.0	1.8	0.6	7.8	2.4	13.8	4.3
19	4 34.8	4 35.5	4 22.2	1.9	0.6	7.9	2.4	13.9	4.3
20	4 35.0	4 35.8	4 22.5	2.0	0.6	8.0	2.5	14.0	4.3
21	4 35.3	4 36.0	4 22.7	2.1	0.6	8.1	2.5	14.1	4.3
22	4 35.5	4 36.3	4 22.9	2.2	0.7	8.2	2.5	14.2	4.4
23	4 35.8	4 36.5	4 23.2	2.3	0.7	8.3	2.6	14.3	4.4
24	4 36.0	4 36.8	4 23.4	2.4	0.7	8.4	2.6	14.4	4.4
25	4 36.3	4 37.0	4 23.7	2.5	0.8	8.5	2.6	14.5	4.5
26	4 36.5	4 37.3	4 23.9	2.6	0.8	8.6	2.7	14.6	4.5
27	4 36.8	4 37.5	4 24.1	2.7	0.8	8.7	2.7	14.7	4.5
28	4 37.0	4 37.8	4 24.4	2.8	0.9	8.8	2.7	14.8	4.6
29	4 37.3	4 38.0	4 24.6	2.9	0.9	8.9	2.7	14.9	4.6
30	4 37.5	4 38.3	4 24.9	3.0	0.9	9.0	2.8	15.0	4.6
31	4 37.8	4 38.5	4 25.1	3.1	1.0	9.1	2.8	15.1	4.7
32	4 38.0	4 38.8	4 25.3	3.2	1.0	9.2	2.8	15.2	4.7
33	4 38.3	4 39.0	4 25.6	3.3	1.0	9.3	2.9	15.3	4.7
34	4 38.5	4 39.3	4 25.8	3.4	1.0	9.4	2.9	15.4	4.7
35	4 38.8	4 39.5	4 26.1	3.5	1.1	9.5	2.9	15.5	4.8
36	4 39.0	4 39.8	4 26.3	3.6	1.1	9.6	3.0	15.6	4.8
37	4 39.3	4 40.0	4 26.5	3.7	1.1	9.7	3.0	15.7	4.8
38	4 39.5	4 40.3	4 26.8	3.8	1.2	9.8	3.0	15.8	4.9
39	4 39.8	4 40.5	4 27.0	3.9	1.2	9.9	3.1	15.9	4.9
40	4 40.0	4 40.8	4 27.2	4.0	1.2	10.0	3.1	16.0	4.9
41	4 40.3	4 41.0	4 27.5	4.1	1.3	10.1	3.1	16.1	5.0
42	4 40.5	4 41.3	4 27.7	4.2	1.3	10.2	3.1	16.2	5.0
43	4 40.8	4 41.5	4 28.0	4.3	1.3	10.3	3.2	16.3	5.0
44	4 41.0	4 41.8	4 28.2	4.4	1.4	10.4	3.2	16.4	5.1
45	4 41.3	4 42.0	4 28.4	4.5	1.4	10.5	3.2	16.5	5.1
46	4 41.5	4 42.3	4 28.7	4.6	1.4	10.6	3.3	16.6	5.1
47	4 41.8	4 42.5	4 28.9	4.7	1.4	10.7	3.3	16.7	5.1
48	4 42.0	4 42.8	4 29.2	4.8	1.5	10.8	3.3	16.8	5.2
49	4 42.3	4 43.0	4 29.4	4.9	1.5	10.9	3.4	16.9	5.2
50	4 42.5	4 43.3	4 29.6	5.0	1.5	11.0	3.4	17.0	5.2
51	4 42.8	4 43.5	4 29.9	5.1	1.6	11.1	3.4	17.1	5.3
52	4 43.0	4 43.8	4 30.1	5.2	1.6	11.2	3.5	17.2	5.3
53	4 43.3	4 44.0	4 30.3	5.3	1.6	11.3	3.5	17.3	5.3
54	4 43.5	4 44.3	4 30.6	5.4	1.7	11.4	3.5	17.4	5.4
55	4 43.8	4 44.5	4 30.8	5.5	1.7	11.5	3.5	17.5	5.4
56	4 44.0	4 44.8	4 31.1	5.6	1.7	11.6	3.6	17.6	5.4
57	4 44.3	4 45.0	4 31.3	5.7	1.8	11.7	3.6	17.7	5.5
58	4 44.5	4 45.3	4 31.5	5.8	1.8	11.8	3.6	17.8	5.5
59	4 44.8	4 45.5	4 31.8	5.9	1.8	11.9	3.7	17.9	5.5
60	4 45.0	4 45.8	4 32.0	6.0	1.9	12.0	3.7	18.0	5.6

19ᵐ s	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
	° ′	° ′	° ′	′	′	′	′	′	′
00	4 45.0	4 45.8	4 32.0	0.0	0.0	6.0	2.0	12.0	3.9
01	4 45.3	4 46.0	4 32.3	0.1	0.0	6.1	2.0	12.1	3.9
02	4 45.5	4 46.3	4 32.5	0.2	0.1	6.2	2.0	12.2	4.0
03	4 45.8	4 46.5	4 32.7	0.3	0.1	6.3	2.0	12.3	4.0
04	4 46.0	4 46.8	4 33.0	0.4	0.1	6.4	2.1	12.4	4.0
05	4 46.3	4 47.0	4 33.2	0.5	0.2	6.5	2.1	12.5	4.1
06	4 46.5	4 47.3	4 33.4	0.6	0.2	6.6	2.1	12.6	4.1
07	4 46.8	4 47.5	4 33.7	0.7	0.2	6.7	2.2	12.7	4.1
08	4 47.0	4 47.8	4 33.9	0.8	0.3	6.8	2.2	12.8	4.2
09	4 47.3	4 48.0	4 34.2	0.9	0.3	6.9	2.2	12.9	4.2
10	4 47.5	4 48.3	4 34.4	1.0	0.3	7.0	2.3	13.0	4.2
11	4 47.8	4 48.5	4 34.6	1.1	0.4	7.1	2.3	13.1	4.3
12	4 48.0	4 48.8	4 34.9	1.2	0.4	7.2	2.3	13.2	4.3
13	4 48.3	4 49.0	4 35.1	1.3	0.4	7.3	2.4	13.3	4.3
14	4 48.5	4 49.3	4 35.4	1.4	0.5	7.4	2.4	13.4	4.4
15	4 48.8	4 49.5	4 35.6	1.5	0.5	7.5	2.4	13.5	4.4
16	4 49.0	4 49.8	4 35.8	1.6	0.5	7.6	2.5	13.6	4.4
17	4 49.3	4 50.0	4 36.1	1.7	0.6	7.7	2.5	13.7	4.5
18	4 49.5	4 50.3	4 36.3	1.8	0.6	7.8	2.5	13.8	4.5
19	4 49.8	4 50.5	4 36.6	1.9	0.6	7.9	2.6	13.9	4.5
20	4 50.0	4 50.8	4 36.8	2.0	0.7	8.0	2.6	14.0	4.6
21	4 50.3	4 51.0	4 37.0	2.1	0.7	8.1	2.6	14.1	4.6
22	4 50.5	4 51.3	4 37.3	2.2	0.7	8.2	2.7	14.2	4.6
23	4 50.8	4 51.5	4 37.5	2.3	0.7	8.3	2.7	14.3	4.6
24	4 51.0	4 51.8	4 37.7	2.4	0.8	8.4	2.7	14.4	4.7
25	4 51.3	4 52.0	4 38.0	2.5	0.8	8.5	2.8	14.5	4.7
26	4 51.5	4 52.3	4 38.2	2.6	0.8	8.6	2.8	14.6	4.7
27	4 51.8	4 52.5	4 38.5	2.7	0.9	8.7	2.8	14.7	4.8
28	4 52.0	4 52.8	4 38.7	2.8	0.9	8.8	2.9	14.8	4.8
29	4 52.3	4 53.1	4 38.9	2.9	0.9	8.9	2.9	14.9	4.8
30	4 52.5	4 53.3	4 39.2	3.0	1.0	9.0	2.9	15.0	4.9
31	4 52.8	4 53.6	4 39.4	3.1	1.0	9.1	3.0	15.1	4.9
32	4 53.0	4 53.8	4 39.7	3.2	1.0	9.2	3.0	15.2	4.9
33	4 53.3	4 54.1	4 39.9	3.3	1.1	9.3	3.0	15.3	5.0
34	4 53.5	4 54.3	4 40.1	3.4	1.1	9.4	3.1	15.4	5.0
35	4 53.8	4 54.6	4 40.4	3.5	1.1	9.5	3.1	15.5	5.0
36	4 54.0	4 54.8	4 40.6	3.6	1.2	9.6	3.1	15.6	5.1
37	4 54.3	4 55.1	4 40.8	3.7	1.2	9.7	3.2	15.7	5.1
38	4 54.5	4 55.3	4 41.1	3.8	1.2	9.8	3.2	15.8	5.1
39	4 54.8	4 55.6	4 41.3	3.9	1.3	9.9	3.2	15.9	5.2
40	4 55.0	4 55.8	4 41.6	4.0	1.3	10.0	3.3	16.0	5.2
41	4 55.3	4 56.1	4 41.8	4.1	1.3	10.1	3.3	16.1	5.2
42	4 55.5	4 56.3	4 42.0	4.2	1.4	10.2	3.3	16.2	5.3
43	4 55.8	4 56.6	4 42.3	4.3	1.4	10.3	3.3	16.3	5.3
44	4 56.0	4 56.8	4 42.5	4.4	1.4	10.4	3.4	16.4	5.3
45	4 56.3	4 57.1	4 42.8	4.5	1.5	10.5	3.4	16.5	5.4
46	4 56.5	4 57.3	4 43.0	4.6	1.5	10.6	3.4	16.6	5.4
47	4 56.8	4 57.6	4 43.2	4.7	1.5	10.7	3.5	16.7	5.4
48	4 57.0	4 57.8	4 43.5	4.8	1.6	10.8	3.5	16.8	5.5
49	4 57.3	4 58.1	4 43.7	4.9	1.6	10.9	3.5	16.9	5.5
50	4 57.5	4 58.3	4 43.9	5.0	1.6	11.0	3.6	17.0	5.5
51	4 57.8	4 58.6	4 44.2	5.1	1.7	11.1	3.6	17.1	5.6
52	4 58.0	4 58.8	4 44.4	5.2	1.7	11.2	3.6	17.2	5.6
53	4 58.3	4 59.1	4 44.7	5.3	1.7	11.3	3.7	17.3	5.6
54	4 58.5	4 59.3	4 44.9	5.4	1.8	11.4	3.7	17.4	5.7
55	4 58.8	4 59.6	4 45.1	5.5	1.8	11.5	3.7	17.5	5.7
56	4 59.0	4 59.8	4 45.4	5.6	1.8	11.6	3.8	17.6	5.7
57	4 59.3	5 00.1	4 45.6	5.7	1.9	11.7	3.8	17.7	5.8
58	4 59.5	5 00.3	4 45.9	5.8	1.9	11.8	3.8	17.8	5.8
59	4 59.8	5 00.6	4 46.1	5.9	1.9	11.9	3.9	17.9	5.8
60	5 00.0	5 00.8	4 46.3	6.0	2.0	12.0	3.9	18.0	5.9

Appendix F-10

20^m INCREMENTS AND CORRECTIONS 21^m

20m	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 00·0	5 00·8	4 46·3	0·0	0·0	6·0	2·1	12·0	4·1
01	5 00·3	5 01·1	4 46·6	0·1	0·0	6·1	2·1	12·1	4·1
02	5 00·5	5 01·3	4 46·8	0·2	0·1	6·2	2·1	12·2	4·2
03	5 00·8	5 01·6	4 47·0	0·3	0·1	6·3	2·2	12·3	4·2
04	5 01·0	5 01·8	4 47·3	0·4	0·1	6·4	2·2	12·4	4·2
05	5 01·3	5 02·1	4 47·5	0·5	0·2	6·5	2·2	12·5	4·3
06	5 01·5	5 02·3	4 47·8	0·6	0·2	6·6	2·3	12·6	4·3
07	5 01·8	5 02·6	4 48·0	0·7	0·2	6·7	2·3	12·7	4·3
08	5 02·0	5 02·8	4 48·2	0·8	0·3	6·8	2·3	12·8	4·4
09	5 02·3	5 03·1	4 48·5	0·9	0·3	6·9	2·4	12·9	4·4
10	5 02·5	5 03·3	4 48·7	1·0	0·3	7·0	2·4	13·0	4·4
11	5 02·8	5 03·6	4 49·0	1·1	0·4	7·1	2·4	13·1	4·5
12	5 03·0	5 03·8	4 49·2	1·2	0·4	7·2	2·5	13·2	4·5
13	5 03·3	5 04·1	4 49·4	1·3	0·4	7·3	2·5	13·3	4·5
14	5 03·5	5 04·3	4 49·7	1·4	0·5	7·4	2·5	13·4	4·6
15	5 03·8	5 04·6	4 49·9	1·5	0·5	7·5	2·6	13·5	4·6
16	5 04·0	5 04·8	4 50·2	1·6	0·5	7·6	2·6	13·6	4·6
17	5 04·3	5 05·1	4 50·4	1·7	0·6	7·7	2·6	13·7	4·7
18	5 04·5	5 05·3	4 50·6	1·8	0·6	7·8	2·7	13·8	4·7
19	5 04·8	5 05·6	4 50·9	1·9	0·6	7·9	2·7	13·9	4·7
20	5 05·0	5 05·8	4 51·1	2·0	0·7	8·0	2·7	14·0	4·8
21	5 05·3	5 06·1	4 51·3	2·1	0·7	8·1	2·8	14·1	4·8
22	5 05·5	5 06·3	4 51·6	2·2	0·8	8·2	2·8	14·2	4·9
23	5 05·8	5 06·6	4 51·8	2·3	0·8	8·3	2·8	14·3	4·9
24	5 06·0	5 06·8	4 52·1	2·4	0·8	8·4	2·9	14·4	4·9
25	5 06·3	5 07·1	4 52·3	2·5	0·9	8·5	2·9	14·5	5·0
26	5 06·5	5 07·3	4 52·5	2·6	0·9	8·6	2·9	14·6	5·0
27	5 06·8	5 07·6	4 52·8	2·7	0·9	8·7	3·0	14·7	5·0
28	5 07·0	5 07·8	4 53·0	2·8	1·0	8·8	3·0	14·8	5·1
29	5 07·3	5 08·1	4 53·3	2·9	1·0	8·9	3·0	14·9	5·1
30	5 07·5	5 08·3	4 53·5	3·0	1·0	9·0	3·1	15·0	5·1
31	5 07·8	5 08·6	4 53·7	3·1	1·1	9·1	3·1	15·1	5·2
32	5 08·0	5 08·8	4 54·0	3·2	1·1	9·2	3·1	15·2	5·2
33	5 08·3	5 09·1	4 54·2	3·3	1·1	9·3	3·2	15·3	5·2
34	5 08·5	5 09·3	4 54·4	3·4	1·2	9·4	3·2	15·4	5·3
35	5 08·8	5 09·6	4 54·7	3·5	1·2	9·5	3·2	15·5	5·3
36	5 09·0	5 09·8	4 54·9	3·6	1·2	9·6	3·3	15·6	5·3
37	5 09·3	5 10·1	4 55·2	3·7	1·3	9·7	3·3	15·7	5·4
38	5 09·5	5 10·3	4 55·4	3·8	1·3	9·8	3·3	15·8	5·4
39	5 09·8	5 10·6	4 55·6	3·9	1·3	9·9	3·4	15·9	5·4
40	5 10·0	5 10·8	4 55·9	4·0	1·4	10·0	3·4	16·0	5·5
41	5 10·3	5 11·1	4 56·1	4·1	1·4	10·1	3·5	16·1	5·5
42	5 10·5	5 11·4	4 56·4	4·2	1·4	10·2	3·5	16·2	5·5
43	5 10·8	5 11·6	4 56·6	4·3	1·5	10·3	3·5	16·3	5·6
44	5 11·0	5 11·9	4 56·8	4·4	1·5	10·4	3·6	16·4	5·6
45	5 11·3	5 12·1	4 57·1	4·5	1·5	10·5	3·6	16·5	5·6
46	5 11·5	5 12·4	4 57·3	4·6	1·6	10·6	3·6	16·6	5·7
47	5 11·8	5 12·6	4 57·5	4·7	1·6	10·7	3·7	16·7	5·7
48	5 12·0	5 12·9	4 57·8	4·8	1·6	10·8	3·7	16·8	5·7
49	5 12·3	5 13·1	4 58·0	4·9	1·7	10·9	3·7	16·9	5·8
50	5 12·5	5 13·4	4 58·3	5·0	1·7	11·0	3·8	17·0	5·8
51	5 12·8	5 13·6	4 58·5	5·1	1·7	11·1	3·8	17·1	5·8
52	5 13·0	5 13·9	4 58·7	5·2	1·8	11·2	3·8	17·2	5·9
53	5 13·3	5 14·1	4 59·0	5·3	1·8	11·3	3·9	17·3	5·9
54	5 13·5	5 14·4	4 59·2	5·4	1·8	11·4	3·9	17·4	5·9
55	5 13·8	5 14·6	4 59·5	5·5	1·9	11·5	3·9	17·5	6·0
56	5 14·0	5 14·9	4 59·7	5·6	1·9	11·6	4·0	17·6	6·0
57	5 14·3	5 15·1	4 59·9	5·7	1·9	11·7	4·0	17·7	6·0
58	5 14·5	5 15·4	5 00·2	5·8	2·0	11·8	4·0	17·8	6·1
59	5 14·8	5 15·6	5 00·4	5·9	2·0	11·9	4·1	17·9	6·1
60	5 15·0	5 15·9	5 00·7	6·0	2·1	12·0	4·1	18·0	6·2

21m	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 15·0	5 15·9	5 00·7	0·0	0·0	6·0	2·2	12·0	4·3
01	5 15·3	5 16·1	5 00·9	0·1	0·0	6·1	2·2	12·1	4·3
02	5 15·5	5 16·4	5 01·1	0·2	0·1	6·2	2·2	12·2	4·4
03	5 15·8	5 16·6	5 01·4	0·3	0·1	6·3	2·3	12·3	4·4
04	5 16·0	5 16·9	5 01·6	0·4	0·1	6·4	2·3	12·4	4·4
05	5 16·3	5 17·1	5 01·8	0·5	0·2	6·5	2·3	12·5	4·5
06	5 16·5	5 17·4	5 02·1	0·6	0·2	6·6	2·4	12·6	4·5
07	5 16·8	5 17·6	5 02·3	0·7	0·3	6·7	2·4	12·7	4·6
08	5 17·0	5 17·9	5 02·6	0·8	0·3	6·8	2·4	12·8	4·6
09	5 17·3	5 18·1	5 02·8	0·9	0·3	6·9	2·5	12·9	4·6
10	5 17·5	5 18·4	5 03·0	1·0	0·4	7·0	2·5	13·0	4·7
11	5 17·8	5 18·6	5 03·3	1·1	0·4	7·1	2·5	13·1	4·7
12	5 18·0	5 18·9	5 03·5	1·2	0·4	7·2	2·6	13·2	4·7
13	5 18·3	5 19·1	5 03·8	1·3	0·5	7·3	2·6	13·3	4·8
14	5 18·5	5 19·4	5 04·0	1·4	0·5	7·4	2·7	13·4	4·8
15	5 18·8	5 19·6	5 04·2	1·5	0·5	7·5	2·7	13·5	4·8
16	5 19·0	5 19·9	5 04·5	1·6	0·6	7·6	2·7	13·6	4·9
17	5 19·3	5 20·1	5 04·7	1·7	0·6	7·7	2·8	13·7	4·9
18	5 19·5	5 20·4	5 04·9	1·8	0·6	7·8	2·8	13·8	4·9
19	5 19·8	5 20·6	5 05·2	1·9	0·7	7·9	2·8	13·9	5·0
20	5 20·0	5 20·9	5 05·4	2·0	0·7	8·0	2·9	14·0	5·0
21	5 20·3	5 21·1	5 05·7	2·1	0·8	8·1	2·9	14·1	5·1
22	5 20·5	5 21·4	5 05·9	2·2	0·8	8·2	2·9	14·2	5·1
23	5 20·8	5 21·6	5 06·1	2·3	0·8	8·3	3·0	14·3	5·1
24	5 21·0	5 21·9	5 06·4	2·4	0·9	8·4	3·0	14·4	5·2
25	5 21·3	5 22·1	5 06·6	2·5	0·9	8·5	3·0	14·5	5·2
26	5 21·5	5 22·4	5 06·9	2·6	0·9	8·6	3·1	14·6	5·2
27	5 21·8	5 22·6	5 07·1	2·7	1·0	8·7	3·1	14·7	5·3
28	5 22·0	5 22·9	5 07·3	2·8	1·0	8·8	3·2	14·8	5·3
29	5 22·3	5 23·1	5 07·6	2·9	1·0	8·9	3·2	14·9	5·3
30	5 22·5	5 23·4	5 07·8	3·0	1·1	9·0	3·2	15·0	5·4
31	5 22·8	5 23·6	5 08·0	3·1	1·1	9·1	3·3	15·1	5·4
32	5 23·0	5 23·9	5 08·3	3·2	1·1	9·2	3·3	15·2	5·4
33	5 23·3	5 24·1	5 08·5	3·3	1·2	9·3	3·3	15·3	5·5
34	5 23·5	5 24·4	5 08·8	3·4	1·2	9·4	3·4	15·4	5·5
35	5 23·8	5 24·6	5 09·0	3·5	1·3	9·5	3·4	15·5	5·6
36	5 24·0	5 24·9	5 09·2	3·6	1·3	9·6	3·4	15·6	5·6
37	5 24·3	5 25·1	5 09·5	3·7	1·3	9·7	3·5	15·7	5·6
38	5 24·5	5 25·4	5 09·7	3·8	1·4	9·8	3·5	15·8	5·7
39	5 24·8	5 25·6	5 10·0	3·9	1·4	9·9	3·5	15·9	5·7
40	5 25·0	5 25·9	5 10·2	4·0	1·4	10·0	3·6	16·0	5·7
41	5 25·3	5 26·1	5 10·4	4·1	1·5	10·1	3·6	16·1	5·8
42	5 25·5	5 26·4	5 10·7	4·2	1·5	10·2	3·7	16·2	5·8
43	5 25·8	5 26·6	5 10·9	4·3	1·5	10·3	3·7	16·3	5·8
44	5 26·0	5 26·9	5 11·1	4·4	1·6	10·4	3·7	16·4	5·9
45	5 26·3	5 27·1	5 11·4	4·5	1·6	10·5	3·8	16·5	5·9
46	5 26·5	5 27·4	5 11·6	4·6	1·6	10·6	3·8	16·6	5·9
47	5 26·8	5 27·6	5 11·9	4·7	1·7	10·7	3·8	16·7	6·0
48	5 27·0	5 27·9	5 12·1	4·8	1·7	10·8	3·9	16·8	6·0
49	5 27·3	5 28·1	5 12·3	4·9	1·8	10·9	3·9	16·9	6·1
50	5 27·5	5 28·4	5 12·6	5·0	1·8	11·0	3·9	17·0	6·1
51	5 27·8	5 28·6	5 12·8	5·1	1·8	11·1	4·0	17·1	6·1
52	5 28·0	5 28·9	5 13·1	5·2	1·9	11·2	4·0	17·2	6·2
53	5 28·3	5 29·1	5 13·3	5·3	1·9	11·3	4·0	17·3	6·2
54	5 28·5	5 29·4	5 13·5	5·4	1·9	11·4	4·1	17·4	6·2
55	5 28·8	5 29·7	5 13·8	5·5	2·0	11·5	4·1	17·5	6·3
56	5 29·0	5 29·9	5 14·0	5·6	2·0	11·6	4·2	17·6	6·3
57	5 29·3	5 30·2	5 14·3	5·7	2·0	11·7	4·2	17·7	6·3
58	5 29·5	5 30·4	5 14·5	5·8	2·1	11·8	4·2	17·8	6·4
59	5 29·8	5 30·7	5 14·7	5·9	2·1	11·9	4·3	17·9	6·4
60	5 30·0	5 30·9	5 15·0	6·0	2·2	12·0	4·3	18·0	6·5

Appendix F-11

POLARIS (POLE STAR) TABLES, 1970

FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE AND FOR AZIMUTH

L.H.A. ARIES	0°–9°	10°–19°	20°–29°	30°–39°	40°–49°	50°–59°	60°–69°	70°–79°	80°–89°	90°–99°	100°–109°	110°–119°
	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 14·2	0 10·2	0 07·6	0 06·7	0 07·4	0 09·6	0 13·4	0 18·6	0 25·0	0 32·4	0 40·7	0 49·5
1	13·7	09·8	07·5	06·7	07·5	09·9	13·9	19·2	25·7	33·2	41·5	50·4
2	13·3	09·5	07·3	06·7	07·7	10·3	14·3	19·8	26·4	34·0	42·4	51·3
3	12·8	09·2	07·2	06·7	07·9	10·6	14·8	20·4	27·1	34·8	43·3	52·2
4	12·4	09·0	07·1	06·8	08·1	11·0	15·3	21·0	27·9	35·7	44·1	53·1
5	0 12·0	0 08·7	0 07·0	0 06·8	0 08·3	0 11·3	0 15·8	0 21·7	0 28·6	0 36·5	0 45·0	0 54·0
6	11·6	08·5	06·9	06·9	08·5	11·7	16·4	22·3	29·4	37·3	45·9	54·9
7	11·2	08·2	06·8	07·0	08·8	12·1	16·9	23·0	30·1	38·1	46·8	55·8
8	10·9	08·0	06·8	07·1	09·1	12·5	17·5	23·6	30·9	39·0	47·7	56·7
9	10·5	07·8	06·7	07·2	09·3	13·0	18·0	24·3	31·7	39·8	48·6	57·6
10	0 10·2	0 07·6	0 06·7	0 07·4	0 09·6	0 13·4	0 18·6	0 25·0	0 32·4	0 40·7	0 49·5	0 58·5
Lat.	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1
°	′	′	′	′	′	′	′	′	′	′	′	′
0	0·5	0·6	0·6	0·6	0·6	0·5	0·5	0·4	0·3	0·2	0·2	0·1
10	·5	·6	·6	·6	·6	·5	·5	·4	·3	·3	·2	·2
20	·5	·6	·6	·6	·6	·5	·5	·4	·4	·3	·3	·3
30	·6	·6	·6	·6	·6	·6	·5	·5	·4	·4	·4	·4
40	0·6	0·6	0·6	0·6	0·6	0·6	0·6	0·5	0·5	0·5	0·5	0·5
45	·6	·6	·6	·6	·6	·6	·6	·6	·6	·5	·5	·5
50	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6
55	·6	·6	·6	·6	·6	·6	·6	·6	·7	·7	·7	·7
60	·6	·6	·6	·6	·6	·6	·7	·7	·7	·8	·8	·8
62	0·7	0·6	0·6	0·6	0·6	0·6	0·7	0·7	0·8	0·8	0·9	0·9
64	·7	·6	·6	·6	·6	·7	·7	·8	·8	·9	0·9	0·9
66	·7	·6	·6	·6	·6	·7	·7	·8	·9	0·9	1·0	1·0
68	0·7	0·6	0·6	0·6	0·6	0·7	0·8	0·8	0·9	1·0	1·1	1·1
Month	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2
	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7
Feb.	·6	·6	·7	·7	·7	·8	·8	·8	·8	·8	·8	·8
Mar.	·5	·5	·6	·6	·7	·7	·8	·8	·9	·9	·9	0·9
Apr.	0·3	0·4	0·4	0·5	0·6	0·6	0·7	0·8	0·8	0·9	0·9	1·0
May	·2	·3	·3	·4	·4	·5	·6	·6	·7	·8	·8	0·9
June	·2	·2	·2	·3	·3	·4	·4	·5	·5	·6	·7	·8
July	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·5	0·6
Aug.	·4	·3	·3	·3	·3	·3	·3	·3	·3	·3	·4	·4
Sept.	·5	·5	·4	·4	·3	·3	·3	·3	·3	·3	·3	·3
Oct.	0·7	0·7	0·6	0·6	0·5	0·4	0·4	0·3	0·3	0·3	0·3	0·2
Nov.	0·9	0·9	0·8	0·7	·7	·6	·5	·5	·4	·3	·3	·3
Dec.	1·0	1·0	1·0	0·9	0·8	0·8	0·7	0·6	0·6	0·5	0·4	0·3
Lat.	AZIMUTH											
°	°	°	°	°	°	°	°	°	°	°	°	°
0	0·4	0·2	0·1	359·9	359·8	359·6	359·5	359·4	359·3	359·2	359·2	359·1
20	0·4	0·3	0·1	359·9	359·8	359·6	359·5	359·4	359·2	359·2	359·1	359·1
40	0·5	0·3	0·1	359·9	359·7	359·5	359·4	359·2	359·1	359·0	358·9	358·9
50	0·6	0·4	0·1	359·9	359·7	359·4	359·2	359·0	358·9	358·8	358·7	358·7
55	0·7	0·4	0·2	359·9	359·6	359·4	359·1	358·9	358·8	358·6	358·5	358·5
60	0·8	0·5	0·2	359·9	359·6	359·3	359·0	358·8	358·6	358·4	358·3	358·3
65	0·9	0·6	0·2	359·8	359·5	359·1	358·8	358·5	358·3	358·1	358·0	357·9

Latitude = Apparent altitude (corrected for refraction) $- 1° + a_0 + a_1 + a_2$

The table is entered with L.H.A. Aries to determine the column to be used; each column refers to a range of 10°. a_0 is taken, with mental interpolation, from the upper table with the units of L.H.A. Aries in degrees as argument; a_1, a_2 are taken, without interpolation, from the second and third tables with arguments latitude and month respectively. a_0, a_1, a_2 are always positive. The final table gives the azimuth of *Polaris*.

Appendix F-12

TABLES FOR INTERPOLATING SUNRISE, MOONRISE, ETC.

TABLE I—FOR LATITUDE

Tabular Interval			Difference between the times for consecutive latitudes															
10°	5°	2°	5m	10m	15m	20m	25m	30m	35m	40m	45m	50m	55m	60m	1h 05m	1h 10m	1h 15m	1h 20m
° ′	° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m
0 30	0 15	0 06	0	0	1	1	1	1	1	2	2	2	2	2	0 02	0 02	0 02	0 02
1 00	0 30	0 12	0	1	1	2	2	3	3	3	4	4	4	5	05	05	05	05
1 30	0 45	0 18	1	1	2	3	3	4	4	5	5	6	7	7	07	07	07	07
2 00	1 00	0 24	1	2	3	4	5	5	6	7	7	8	9	10	10	10	10	10
2 30	1 15	0 30	1	2	4	5	6	7	8	9	9	10	11	12	12	13	13	13
3 00	1 30	0 36	1	3	4	6	7	8	9	10	11	12	13	14	0 15	0 15	0 16	0 16
3 30	1 45	0 42	2	3	5	7	8	10	11	12	13	14	16	17	18	18	19	19
4 00	2 00	0 48	2	4	6	8	9	11	13	14	15	16	18	19	20	21	22	22
4 30	2 15	0 54	2	4	7	9	11	13	15	16	18	19	21	22	23	24	25	26
5 00	2 30	1 00	2	5	7	10	12	14	16	18	20	22	23	25	26	27	28	29
5 30	2 45	1 06	3	5	8	11	13	16	18	20	22	24	26	28	0 29	0 30	0 31	0 32
6 00	3 00	1 12	3	6	9	12	14	17	20	22	24	26	29	31	32	33	34	36
6 30	3 15	1 18	3	6	10	13	16	19	22	24	26	29	31	34	36	37	38	40
7 00	3 30	1 24	3	7	10	14	17	20	23	26	29	31	34	37	39	41	42	44
7 30	3 45	1 30	4	7	11	15	18	22	25	28	31	34	37	40	43	44	46	48
8 00	4 00	1 36	4	8	12	16	20	23	27	30	34	37	41	44	0 47	0 48	0 51	0 53
8 30	4 15	1 42	4	8	13	17	21	25	29	33	36	40	44	48	0 51	0 53	0 56	0 58
9 00	4 30	1 48	4	9	13	18	22	27	31	35	39	43	47	52	0 55	0 58	1 01	1 04
9 30	4 45	1 54	5	9	14	19	24	28	33	38	42	47	51	56	1 00	1 04	1 08	1 12
10 00	5 00	2 00	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20

Table I is for interpolating the L.M.T. of sunrise, twilight, moonrise, etc., for latitude. It is to be entered, in the appropriate column on the left, with the difference between true latitude and the nearest tabular latitude which is *less* than the true latitude; and with the argument at the top which is the nearest value of the difference between the times for the tabular latitude and the next higher one; the correction so obtained is applied to the time for the tabular latitude; the sign of the correction can be seen by inspection. It is to be noted that the interpolation is not linear, so that when using this table it is essential to take out the tabular phenomenon for the latitude *less* than the true latitude.

TABLE II—FOR LONGITUDE

Long. East or West	Difference between the times for given date and preceding date (for east longitude) or for given date and following date (for west longitude)																	
	10m	20m	30m	40m	50m	60m	1h + 10m	1h + 20m	1h + 30m	1h + 40m	1h + 50m	1h + 60m	2h 10m	2h 20m	2h 30m	2h 40m	2h 50m	3h 00m
°	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m	h m	h m
0	0	0	0	0	0	0	0	0	0	0	0	0	0 00	0 00	0 00	0 00	0 00	0 00
10	0	1	1	1	1	2	2	2	2	3	3	3	04	04	04	04	05	05
20	1	1	2	2	3	3	4	4	5	6	6	7	07	08	08	09	09	10
30	1	2	2	3	4	5	6	7	7	8	9	10	11	12	12	13	14	15
40	1	2	3	4	6	7	8	9	10	11	12	13	14	16	17	18	19	20
50	1	3	4	6	7	8	10	11	12	14	15	17	0 18	0 19	0 21	0 22	0 24	0 25
60	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30
70	2	4	6	8	10	12	14	16	17	19	21	23	25	27	29	31	33	35
80	2	4	7	9	11	13	16	18	20	22	24	27	29	31	33	36	38	40
90	2	5	7	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45
100	3	6	8	11	14	17	19	22	25	28	31	33	0 36	0 39	0 42	0 44	0 47	0 50
110	3	6	9	12	15	18	21	24	27	31	34	37	40	43	46	49	0 52	0 55
120	3	7	10	13	17	20	23	27	30	33	37	40	43	47	50	53	0 57	1 00
130	4	7	11	14	18	22	25	29	32	36	40	43	47	51	54	0 58	1 01	1 05
140	4	8	12	16	19	23	27	31	35	39	43	47	51	54	0 58	1 02	1 06	1 10
150	4	8	13	17	21	25	29	33	38	42	46	50	0 54	0 58	1 03	1 07	1 11	1 15
160	4	9	13	18	22	27	31	36	40	44	49	53	0 58	1 02	1 07	1 11	1 16	1 20
170	5	9	14	19	24	28	33	38	42	47	52	57	1 01	1 06	1 11	1 16	1 20	1 25
180	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20	1 25	1 30

Table II is for interpolating the L.M.T. of moonrise, moonset and the Moon's meridian passage for longitude. It is entered with longitude and with the difference between the times for the given date and for the preceding date (in east longitudes) or following date (in west longitudes). The correction is normally *added* for west longitudes and *subtracted* for east longitudes, but if, as occasionally happens, the times become earlier each day instead of later, the signs of the corrections must be reversed.

Appendix G-1

DECLINATION SAME NAME AS LATITUDE

Lat. 34°

22° 30′				23° 00′				23° 30′				H.A.
Alt.			Az.	Alt.			Az.	Alt.			Az.	
° ′	Δd	Δt	°	° ′	Δd	Δt	°	° ′	Δd	Δt	°	°
78 30.0	1.0	03	180.0	79 00.0	1.0	04	180.0	79 30.0	1.0	04	180.0	00
78 28.0	1.0	10	175.4	78 57.9	1.0	10	175.2	79 27.8	1.0	11	175.0	1
78 22.0	99	16	170.8	78 51.7	99	17	170.4	79 21.3	99	18	170.0	2
78 12.1	98	23	166.3	78 41.4	98	24	165.8	79 10.6	97	24	165.2	3
77 58.5	96	28	162.0	78 27.3	96	30	161.3	78 56.0	95	31	160.5	4
77 41.4	94	34	157.8	78 09.6	94	35	157.0	78 37.6	93	36	156.1	05
77 21.0	92	39	153.8	77 48.5	91	40	152.9	78 15.8	90	42	151.9	6
76 57.6	89	44	150.1	77 24.3	89	45	149.0	77 50.8	88	46	147.9	7
76 31.5	87	48	146.5	76 57.4	86	49	145.4	77 23.0	85	50	144.2	8
76 02.8	84	52	143.2	76 28.0	83	53	142.0	76 52.8	82	54	140.8	9
75 31.9	82	55	140.0	75 56.3	81	56	138.9	76 20.3	79	57	137.6	10
74 59.0	79	58	137.1	75 22.6	78	59	135.9	75 45.8	77	60	134.6	1
74 24.3	77	61	134.4	74 47.1	75	62	133.2	75 09.5	74	63	131.9	2
73 48.0	74	63	131.8	74 10.1	73	64	130.6	74 31.8	71	65	129.3	3
73 10.3	72	65	129.5	73 31.7	71	66	128.2	73 52.7	69	67	127.0	4
72 31.2	70	67	127.2	72 52.0	69	68	126.0	73 12.4	67	69	124.8	15
71 51.1	68	69	125.2	72 11.3	66	70	124.0	72 31.0	65	70	122.7	6
71 10.0	66	70	123.2	71 29.5	65	71	122.0	71 48.7	63	72	120.8	7
70 27.9	64	71	121.4	70 47.0	63	72	120.2	71 05.6	61	73	119.0	8
69 45.0	63	73	119.7	70 03.6	61	73	118.5	70 21.7	60	74	117.3	9

Lat. 35°

H.A.	24° 00′				24° 30′			
	Alt.			Az.	Alt.			Az.
°	° ′	Δd	Δt	°	° ′	Δd	Δt	°
00	79 00.0	1.0	03	180.0	79 30.0	1.0	04	180.0
1	78 57.9	1.0	10	175.2	79 27.9	1.0	11	175.0
2	78 51.8	99	17	170.5	79 21.5	99	18	170.1
3	78 41.8	98	23	165.9	79 11.0	97	24	165.3
4	78 27.9	96	29	161.4	78 56.6	95	30	160.7
05	78 10.5	94	35	157.1	78 38.6	93	36	156.3
6	77 49.8	91	40	153.1	78 17.1	91	41	152.1
7	77 26.1	89	44	149.2	77 52.6	88	45	148.1
8	76 59.6	86	48	145.6	77 25.3	85	50	144.4
9	76 30.6	84	52	142.2	76 55.5	82	53	141.0
10	75 59.5	81	55	139.1	76 23.6	80	57	137.8
1	75 26.3	78	58	136.1	75 49.6	77	59	134.8
2	74 51.4	76	61	133.4	75 13.9	74	62	132.1
3	74 14.9	73	63	130.8	74 36.7	72	64	129.5
4	73 37.0	71	65	128.4	73 58.2	70	66	127.1
15	72 57.9	69	67	126.2	73 18.4	67	68	124.9
6	72 17.7	67	69	124.1	72 37.6	65	70	122.9
7	71 36.6	65	70	122.2	71 55.9	64	71	120.9
8	70 54.5	63	71	120.3	71 13.3	62	72	119.1
9	70 11.8	62	72	118.6	70 30.0	60	73	117.4
20	69 28.3	60	73	117.0	69 46.1	59	74	115.8
1	68 44.2	59	74	115.5	69 01.6	57	75	114.3
2	67 59.6	57	75	114.0	68 16.6	56	76	112.9
3	67 14.4	56	76	112.7	67 31.1	55	76	111.6
4	66 28.9	55	77	111.4	66 45.2	54	77	110.3
25	65 42.9	54	77	110.2	65 58.9	53	78	109.1

Lat. 35°

H.A.	12° 00′				12° 30′				13° 00′			
	Alt.			Az.	Alt.			Az.	Alt.			Az.
°	° ′	Δd	Δt	°	° ′	Δd	Δt	°	° ′	Δd	Δt	°
00	67 00.0	1.0	02	180.0	67 30.0	1.0	02	180.0	68 00.0	1.0	02	180.0
1	66 58.9	1.0	05	177.5	67 28.9	1.0	05	177.4	67 58.9	1.0	06	177.4
2	66 55.7	1.0	09	175.0	67 25.6	1.0	09	174.9	67 55.5	1.0	09	174.8
3	66 50.4	99	12	172.5	67 20.2	99	13	172.4	67 50.0	99	13	172.2
4	66 42.9	99	16	170.1	67 12.6	99	16	169.9	67 42.3	99	16	169.7
05	66 33.4	98	19	167.6	67 02.9	98	20	167.4	67 32.4	98	20	167.2
6	66 21.9	98	23	165.2	66 51.2	98	23	165.0	67 20.4	97	23	164.7
7	66 08.4	97	26	162.9	66 37.4	97	26	162.6	[illegible] 06.4	97	27	162.2
8	65 52.9	96	29	160.5	66 21.7	96	29	160.2	66 50.5	96	30	159.8
9	65 35.6	95	32	158.3	66 04.1	95	32	157.9	66 32.6	95	33	157.5
10	65 16.6	94	35	156.0	65 44.7	94	35	155.6	66 12.8	94	36	155.2
1	64 55.7	93	37	153.9	65 23.6	93	38	153.4	65 51.4	92	30	153.0
2	64 33.3	92	40	151.7	65 00.8	92	41	151.3	65 28.2	91	41	150.8
3	64 09.2	91	43	149.7	64 36.4	90	43	149.2	65 03.4	90	44	148.7
4	63 43.7	89	45	147.7	64 10.5	89	46	147.2	64 37.1	89	46	146.6

Lat. 33°

22° 30′				23° 00′				23° 30′				H.A.
Alt.			Az.	Alt.			Az.	Alt.			Az.	
° ′	Δd	Δt	°	° ′	Δd	Δt	°	° ′	Δd	Δt	°	°
79 30.0	1.0	04	180.0	80 00.0	1.0	04	180.0	80 30.0	1.0	04	180.0	00
79 27.8	1.0	11	174.9	79 57.7	1.0	12	174.7	80 27.6	1.0	12	174.5	1
79 21.2	99	18	170.0	79 50.8	99	19	169.5	80 20.3	98	20	169.0	2
79 10.3	97	25	165.1	79 39.4	97	26	164.4	80 08.4	97	27	163.7	3
78 55.3	95	31	160.4	79 23.8	95	32	159.6	79 52.2	94	34	158.7	4
78 36.6	93	37	155.9	79 04.4	92	38	155.0	79 32.0	92	40	153.9	05
78 14.4	90	42	151.7	78 41.4	89	44	150.6	79 08.1	89	45	149.4	6
77 49.0	87	47	147.8	78 15.1	86	48	146.6	78 40.9	85	50	145.3	7
77 20.8	85	51	144.1	77 46.0	83	53	142.8	78 10.9	82	54	141.5	8
76 50.1	82	55	140.6	77 14.4	80	56	139.3	77 38.3	79	58	137.9	9
76 17.0	79	58	137.4	76 40.5	78	60	136.1	77 03.5	76	61	134.7	10
75 42.0	76	61	134.5	76 04.7	75	63	133.1	76 26.8	73	64	131.7	1
75 05.3	74	64	131.7	75 27.1	72	65	130.4	75 48.5	70	66	129.0	2
74 27.0	71	66	129.2	74 48.1	69	67	127.8	75 08.6	68	68	126.4	3
73 47.3	69	68	126.8	74 07.7	67	69	125.5	74 27.5	65	70	124.1	4
73 06.5	66	70	124.6	73 26.2	65	71	123.3	73 45.4	63	72	122.0	15
72 24.6	64	71	122.6	72 43.6	63	72	121.3	73 02.2	61	73	120.0	6
71 41.7	62	73	120.7	72 00.2	61	74	119.4	72 18.2	59	75	118.1	7
70 58.0	61	74	118.9	71 16.0	59	75	117.7	71 33.5	57	76	116.4	8
70 13.6	59	75	117.2	70 31.1	57	76	116.0	70 48.1	56	77	114.8	9

Lat 36°

H.A.	56° 30′				57° 00′			
	Alt.			Az.	Alt.			Az.
65	42 45.3	05	55	42.9	42 46.7	05	54	42.3
6	42 12.2	07	55	42.9	42 14.0	06	54	42.2
7	41 39.2	08	55	42.9	41 41.4	07	54	42.2
8	41 06.2	09	55	42.9	41 08.9	09	54	42.2
9	40 33.3	11	55	42.8	40 36.4	10	54	42.1
70	40 00.4	12	55	42.7	40 03.8	12	54	42.0
1	39 27.5	13	55	42.6	39 31.5	13	54	42.0
2	38 54.7	15	54	42.5	38 59.1	14	54	41.9
3	38 22.0	16	54	42.3	38 26.7	15	54	41.7
4	37 49.4	17	54	42.2	37 54.5	17	54	41.6

Appendix G-2

DECLINATION CONTRARY NAME TO LATITUDE

Lat. 33°

21° 30′ Alt. ° ′	Δd	Δt	Az. °	22° 00′ Alt. ° ′	Δd	Δt	Az. °	22° 30′ Alt. ° ′	Δd	Δt	Az. °	23° 00′ Alt. ° ′	Δd	Δt	Az. °	23° 30′ Alt. ° ′	Δd	Δt	Az. °	H.A. °
35 30.0	1.0	01	180.0	35 00.0	1.0	01	180.0	34 30.0	1.0	01	180.0	34 00.0	1.0	01	180.0	33 30.0	1.0	01	180.0	00
35 29.5	1.0	02	178.9	34 59.5	1.0	02	178.9	34 29.5	1.0	02	178.9	33 59.5	1.0	02	178.9	33 29.5	1.0	02	178.9	1
35 28.0	1.0	04	177.7	34 58.0	1.0	04	177.7	34 28.0	1.0	04	177.8	33 58.1	1.0	04	177.8	33 28.1	1.0	04	177.8	2
35 25.5	1.0	06	176.6	34 55.5	1.0	06	176.6	34 25.6	1.0	06	176.6	33 55.6	1.0	06	176.7	33 25.7	1.0	06	176.7	3
35 22.0	1.0	08	175.4	34 52.1	1.0	07	175.5	34 22.1	1.0	07	175.5	33 52.2	1.0	07	175.6	33 22.3	1.0	07	175.6	4
35 17.5	1.0	09	174.3	34 47.6	1.0	09	174.4	34 17.7	1.0	09	174.4	33 47.8	1.0	09	174.5	33 17.9	1.0	09	174.5	05
35 12.0	99	11	173.2	34 42.2	99	11	173.2	34 12.3	99	11	173.3	33 42.5	99	10	173.4	33 12.7	99	10	173.4	6
35 05.5	99	12	172.0	34 35.7	99	12	172.1	34 06.0	99	12	172.2	33 36.2	99	12	172.3	33 06.4	99	12	172.3	7
34 58.0	99	14	170.9	34 28.3	99	14	171.0	33 58.6	99	14	171.1	33 28.9	99	14	171.2	32 59.2	99	14	171.2	8
34 49.6	99	16	169.8	34 20.0	99	16	169.9	33 50.4	99	15	170.0	33 20.7	99	15	170.1	32 51.1	99	15	170.2	9

Lat. 35°

22° 30′ Alt. ° ′	Δd	Δt	Az. °	23° 00′ Alt. ° ′	Δd	Δt	Az. °	H.A. °
32 30.0	1.0	01	180.0	32 00.0	1.0	01	180.0	00
32 29.5	1.0	02	178.9	31 59.6	1.0	02	178.9	1
32 28.1	1.0	04	177.8	31 58.2	1.0	04	177.8	2
32 25.8	1.0	05	176.7	31 55.8	1.0	05	176.8	3
32 22.5	1.0	07	175.6	31 52.6	1.0	07	175.7	4
32 18.3	1.0	08	174.5	31 48.4	1.0	08	174.6	05
32 13.2	99	10	173.4	31 43.3	99	10	173.5	6
32 07.1	99	12	172.3	31 37.3	99	12	172.4	7
32 00.1	99	13	171.3	31 30.3	99	13	171.4	8
31 52.2	99	15	170.2	31 22.5	99	14	170.3	9
31 43.4	99	16	169.1	31 13.8	99	16	169.2	10
31 33.7	98	18	168.1	31 04.1	98	17	168.2	1
31 23.0	98	19	167.0	30 53.6	98	19	167.1	2
31 11.5	98	21	166.0	30 42.2	98	20	166.1	3
30 59.1	97	22	164.9	30 29.9	97	22	165.0	4
30 45.9	97	23	163.8	30 16.8	97	23	164.0	15
30 31.8	97	25	162.9	30 02.8	97	25	163.0	6
30 16.8	96	26	161.8	29 48.0	96	26	161.9	7
30 01.0	96	28	160.8	29 32.3	96	27	160.9	8
29 44.4	95	29	159.7	29 15.8	95	29	159.9	9
29 27.0	95	30	158.7	28 58.5	95	30	158.9	20
29 08.8	94	32	157.7	28 40.5	94	31	157.9	1
28 49.7	94	33	156.7	28 21.6	94	33	156.9	2
28 29.9	93	34	155.7	28 02.0	93	34	156.0	3
28 09.4	92	35	154.8	27 41.5	92	35	155.0	4
27 48.1	92	37	153.8	27 20.4	92	36	154.0	25
27 26.0	91	38	152.8	26 58.5	91	38	153.1	6
27 03.2	90	39	151.9	26 35.9	90	39	152.1	7
26 39.7	89	40	150.9	26 12.6	89	40	151.2	8
26 15.5	89	41	150.0	25 48.5	89	41	150.3	9
25 50.6	89	43	149.1	25 23.9	89	42	149.4	30
25 25.0	88	44	148.3	24 58.4	88	43	148.5	1
24 58.8	88	45	147.3	24 32.5	88	44	147.6	2
24 31.9	87	46	146.4	24 05.8	87	45	146.7	3
24 04.4	86	47	145.5	23 38.5	86	46	145.8	4

Lat. 33°

H.A. °	24° 00′ Alt. ° ′	Δd	Δt	Az. °	24° 30′ Alt. ° ′	Δd	Δt	Az. °
00	33 00.0	1.0	01	180.0	32 30.0	1.0	01	180.0
1	32 59.5	1.0	02	178.9	32 29.5	1.0	02	178.9
2	32 58.1	1.0	04	177.8	32 28.1	1.0	04	177.8
3	32 55.7	1.0	06	176.7	32 25.7	1.0	06	176.8
4	32 52.4	1.0	07	175.6	32 22.4	1.0	07	175.7
05	32 48.1	1.0	09	174.6	32 18.2	1.0	09	174.6
6	32 42.8	99	10	173.5	32 13.0	99	10	173.5
7	32 36.6	99	12	172.4	32 06.9	99	12	172.5
8	32 29.5	99	13	171.3	31 59.8	99	13	171.4
9	32 21.5	99	15	170.3	31 51.8	99	15	170.4
10	32 12.5	99	16	169.2	31 42.9	99	16	169.3
1	32 02.6	98	18	168.1	31 33.1	98	18	168.2
2	31 51.8	98	20	167.1	31 22.4	98	19	167.2
3	31 40.1	98	21	166.0	31 10.8	98	21	166.2
4	31 27.5	97	22	165.0	30 58.4	97	22	165.1
15	31 14.0	97	24	163.9	30 45.0	97	24	164.1

Appendix H

MECHANICS OF "ERROR FINDING" IN SIGHT REDUCTION BY HO 214

It is not unusual for a student of celestial navigation to make frequent errors in solving for a line of position; hence the following table illustrates the mechanics of "error finding."

A. If t exceeds values given in HO 214—

1. Check date, ZD, and GMT
2. Check longitude. East λ is added and west λ subtracted in the step between GHA and LHA.
3. Check conversion of LHA to t.
4. Check GHA in Nautical Almanac.
5. If working a star sight, check SHA and insure that the GHA as taken from the Almanac is the GHA of ♈.
6. Search for arithmetical error.

B. If Ht differs from Ho (or Hs) by several degrees—

1. Check declination. Note whether latitude and declination are of same name or of contrary name.
2. Check assumed latitude.
3. Assume possible error in t.
4. Search for arithmetical error.

C. If Hc differs from Ho by 1 or 2 degrees ("a" exceeds 60 mi.)—

1. Check assumed longitude.
2. Check Greenwich date.
3. Check GMT.
4. If correction to Hs is large (as in a moon sight) check sign of correction.
5. Check sign of correction to Ht.
6. Check values copied from HO 214.
7. Search for arithmetical error.

D. If results fail to plot favorably—

1. Check labels and try to isolate LOP (or LOP's) in error. Keep in mind your DR position, and possible set and drift. Then carry out steps 2 to 9 for sights isolated.
2. Check conversion of WT to ZT.
3. Check AP's and their advance.
4. Check conversion of azimuth angle to azimuth.
5. Check label of intercept.
6. Check correction to Ht and the sign of that correction.
7. Check the sign of correction applied to Hs to obtain Ho.
8. Check sextant altitude corrections.
9. Check the accuracy of your plot.
10. Search for arithmetical error.

Appendix I-1

LAT 40°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	CAPELLA		ALDEBARAN		Diphda		ALTAIR		VEGA		Kochab	
0	34 40	056	26 53	091	31 00	168	26 22	259	29 39	298	27 49	348
1	35 18	056	27 39	091	31 08	170	25 37	260	28 58	298	27 40	348
2	35 57	057	28 25	092	31 16	171	24 51	260	28 18	298	27 31	349
3	36 35	057	29 11	093	31 23	172	24 06	261	27 37	299	27 22	349
4	37 14	057	29 57	093	31 29	173	23 21	262	26 57	299	27 13	349
5	37 52	058	30 43	094	31 35	174	22 35	262	26 17	300	27 04	349
6	38 31	058	31 29	095	31 39	175	21 50	263	25 37	300	26 56	350
7	39 10	058	32 14	095	31 42	176	21 04	264	24 58	301	26 47	350
8	39 49	059	33 00	096	31 45	177	20 18	264	24 18	301	26 39	350
9	40 29	059	33 46	097	31 47	178	19 32	265	23 39	302	26 32	350
10	41 08	059	34 31	097	31 48	180	18 47	266	23 00	302	26 24	351
11	41 48	059	35 17	098	31 47	181	18 01	266	22 21	303	26 17	351
12	42 27	060	36 02	099	31 46	182	17 15	267	21 43	303	26 09	351
13	43 07	060	36 48	100	31 45	183	16 29	268	21 04	304	26 02	351
14	43 47	060	37 33	100	31 42	184	15 43	268	20 26	304	25 56	352
	CAPELLA		ALDEBARAN		Diphda		Alpheratz		DENEB		Kochab	
15	44 27	061	38 18	101	31 38	185	74 20	229	43 10	299	25 49	352
16	45 07	061	39 03	102	31 34	186	73 45	231	42 30	299	25 43	352
17	45 47	061	39 48	103	31 28	187	73 09	233	41 50	299	25 37	353
18	46 27	061	40 33	103	31 22	188	72 31	236	41 10	300	25 31	353
19	47 08	062	41 18	104	31 15	190	71 53	237	40 30	300	25 25	353
20	47 48	062	42 02	105	31 07	191	71 14	239	39 50	300	25 20	353
21	48 29	062	42 46	106	30 58	192	70 34	241	39 10	301	25 15	354
22	49 09	062	43 31	107	30 48	193	69 53	243	38 31	301	25 10	354
23	49 50	063	44 14	108	30 37	194	69 12	244	37 52	301	25 05	354
24	50 31	063	44 58	108	30 26	195	68 31	246	37 12	302	25 00	355
25	51 12	063	45 42	109	30 13	196	67 48	247	36 33	302	24 56	355
26	51 53	063	46 25	110	30 00	197	67 06	248	35 54	302	24 52	355
27	52 34	063	47 08	111	29 46	198	66 23	250	35 16	303	24 48	355
28	53 15	064	47 51	112	29 31	199	65 40	251	34 37	303	24 45	356
29	53 56	064	48 33	113	29 16	200	64 56	252	33 59	303	24 41	356
	CAPELLA		BETELGEUSE		RIGEL		Diphda		Alpheratz		DENEB	
30	54 38	064	28 51	106	24 26	126	29 00	201	64 12	253	33 20	304
31	55 19	064	29 35	106	25 03	127	28 42	202	63 28	254	32 42	304
32	56 00	064	30 19	107	25 39	128	28 24	203	62 44	255	32 04	304
33	56 42	064	31 03	108	26 16	129	28 06	204	61 59	256	31 26	305
34	57 23	065	31 47	109	26 51	129	27 46	205	61 14	257	30 49	305
35	58 05	065	32 30	110	27 27	130	27 26	206	60 29	258	30 11	306
36	58 46	065	33 13	110	28 01	131	27 05	207	59 44	259	29 34	306
37	59 28	065	33 56	111	28 36	132	26 44	208	58 59	260	28 57	306
38	60 10	065	34 39	112	29 10	133	26 22	209	58 14	261	28 20	307
39	60 51	065	35 21	113	29 43	134	25 59	210	57 28	262	27 43	307
40	61 33	065	36 04	114	30 16	135	25 35	211	56 43	263	27 07	308
41	62 15	065	36 46	115	30 48	136	25 11	212	55 57	263	26 31	308
42	62 55	065	37 27	116	31 20	137	24 46	213	55 11	264	25 54	308
43	63 38	065	38 08	116	31 51	138	24 21	214	54 26	265	25 18	309
44	64 20	065	38 49	117	32 21	139	23 54	215	53 40	266	24 43	309
	Dubhe		POLLUX		BETELGEUSE		RIGEL		Alpheratz		DENEB	
45	22 41	026	31 45	078	39 30	118	32 51	140	52 54	266	24 07	310
46	23 01	026	32 30	079	40 10	119	33 21	141	52 08	267	23 32	310
47	23 22	027	33 15	079	40 50	120	33 49	142	51 22	268	22 57	311
48	23 43	027	34 00	080	41 30	121	34 17	143	50 36	268	22 22	311
49	24 04	027	34 45	080	42 09	122	34 45	144	49 50	269	21 47	311
50	24 25	028	35 31	081	42 48	123	35 11	145	49 04	270	21 13	312
51	24 47	028	36 16	082	43 26	124	35 37	146	48 18	270	20 39	312
52	25 09	028	37 01	082	44 04	125	36 02	147	47 33	271	20 05	313
53	25 31	029	37 47	083	44 41	126	36 27	148	46 47	272	19 31	313
54	25 53	029	38 33	083	45 18	127	36 50	150	46 01	272	18 58	314
55	26 15	029	39 18	084	45 54	129	37 13	151	45 15	273	18 25	314
56	26 38	030	40 04	084	46 29	130	37 35	152	44 29	273	17 52	315
57	27 01	030	40 50	085	47 04	131	37 56	153	43 43	274	17 19	315
58	27 24	030	41 36	086	47 39	132	38 17	154	42 57	275	16 47	316
59	27 47	031	42 21	086	48 13	133	38 36	155	42 11	275	16 15	316
	Dubhe		POLLUX		PROCYON		SIRIUS		RIGEL		Alpheratz	
60	28 11	031	43 07	087	30 19	110	21 46	138	38 55	157	41 26	276
61	28 35	031	43 53	087	31 02	111	22 17	138	39 13	158	40 40	276
62	28 59	032	44 39	088	31 45	112	22 47	139	39 30	159	39 54	277
63	29 23	032	45 25	089	32 27	113	23 17	140	39 46	160	39 09	277
64	29 47	032	46 11	089	33 09	114	23 46	141	40 01	162	38 23	278
65	30 11	032	46 57	090	33 51	115	24 15	142	40 15	163	37 38	279
66	30 36	033	47 43	090	34 33	115	24 43	143	40 28	164	36 52	279
67	31 01	033	48 29	091	35 14	116	25 10	144	40 40	165	36 07	280
68	31 26	033	49 15	092	35 55	117	25 37	145	40 51	167	35 22	280
69	31 51	033	50 01	092	36 36	118	26 03	146	41 01	168	34 36	281
70	32 17	034	50 47	093	37 16	119	26 28	147	41 10	169	33 51	281
71	32 42	034	51 33	094	37 56	120	26 53	148	41 18	171	33 06	282
72	33 08	034	52 18	095	38 36	121	27 18	149	41 25	172	32 21	282
73	33 34	034	53 04	095	39 15	122	27 41	150	41 31	173	31 36	283
74	34 00	035	53 50	096	39 54	123	28 04	151	41 36	174	30 52	283
	Dubhe		REGULUS		PROCYON		SIRIUS		ALDEBARAN		Hamal	
75	34 26	035	18 02	089	40 32	124	28 26	152	65 45	196	49 39	259
76	34 52	035	18 48	090	41 10	125	28 48	153	65 31	198	48 54	260
77	35 18	035	19 34	090	41 47	126	29 08	154	65 16	200	48 09	261
78	35 45	035	20 20	091	42 24	127	29 28	155	65 00	202	47 23	261
79	36 12	036	21 05	092	43 01	128	29 48	156	64 42	204	46 38	262
80	36 38	036	21 51	092	43 37	129	30 06	157	64 22	206	45 52	263
81	37 05	036	22 37	093	44 12	130	30 24	158	64 01	209	45 07	264
82	37 32	036	23 23	094	44 47	131	30 41	159	63 38	211	44 21	264
83	37 59	036	24 09	094	45 21	133	30 57	160	63 14	212	43 35	265
84	38 26	036	24 55	095	45 54	134	31 12	161	62 49	214	42 49	266
85	38 54	037	25 41	096	46 27	135	31 27	162	62 22	216	42 03	266
86	39 21	037	26 26	096	46 59	136	31 41	163	61 55	218	41 18	267
87	39 49	037	27 12	097	47 31	137	31 53	164	61 26	220	40 32	268
88	40 16	037	27 58	098	48 02	139	32 05	165	60 56	221	39 46	268
89	40 41	037	28 43	098	48 32	140	32 16	167	60 25	223	39 00	269

LAT 40°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	Dubhe		REGULUS		PROCYON		SIRIUS		ALDEBARAN		Hamal	
90	41 12	037	29 29	099	49 01	141	32 27	168	59 53	225	38 14	270
91	41 39	037	30 14	100	49 29	143	32 36	169	59 20	226	37 28	270
92	42 07	037	30 59	101	49 56	144	32 45	170	58 47	228	36 42	271
93	42 35	037	31 44	101	50 23	145	32 52	171	58 12	229	35 56	272
94	43 03	038	32 29	102	50 49	147	32 59	172	57 37	231	35 10	272
95	43 31	038	33 14	103	51 13	148	33 05	173	57 01	232	34 24	273
96	43 59	038	33 59	104	51 37	150	33 10	174	56 24	233	33 38	274
97	44 27	038	34 44	104	51 59	151	33 14	176	55 47	235	32 52	274
98	44 56	038	35 28	105	52 21	153	33 17	177	55 09	236	32 07	275
99	45 24	038	36 12	106	52 42	154	33 19	178	54 31	237	31 21	275
100	45 52	038	36 56	107	53 01	156	33 20	179	53 52	238	30 35	276
101	46 20	038	37 40	107	53 19	157	33 20	180	53 13	240	29 49	277
102	46 48	038	38 24	108	53 36	159	33 20	181	52 33	241	29 04	277
103	47 17	038	39 08	109	53 52	161	33 18	182	51 52	242	28 18	278
104	47 45	038	39 51	110	54 07	162	33 16	184	51 12	243	27 33	278
	Dubhe		REGULUS		PROCYON		SIRIUS		ALDEBARAN		CAPELLA	
105	48 13	038	40 34	111	54 20	164	33 12	185	50 31	244	69 47	296
106	48 41	038	41 17	112	54 32	166	33 08	186	49 49	245	69 05	296
107	49 09	038	41 59	113	54 43	167	33 03	187	49 07	246	68 24	295
108	49 37	038	42 42	114	54 52	169	32 57	188	48 25	247	67 42	295
109	50 05	038	43 24	115	55 00	171	32 50	189	47 43	248	67 01	295
110	50 33	037	44 05	115	55 07	172	32 42	190	47 00	249	66 19	295
111	51 01	037	44 47	116	55 12	174	32 33	192	46 17	250	65 37	295
112	51 29	037	45 28	117	55 16	176	32 24	193	45 33	251	64 56	295
113	51 57	037	46 08	118	55 19	178	32 13	194	44 50	252	64 14	295
114	52 25	037	46 48	119	55 20	179	32 02	195	44 06	253	63 32	295
115	52 52	037	47 28	121	55 19	181	31 50	196	43 22	253	62 51	295
116	53 20	037	48 08	122	55 18	183	31 36	197	42 38	254	62 09	295
117	53 47	036	48 47	123	55 15	185	31 22	198	41 54	255	61 27	295
118	54 14	036	49 25	124	55 10	186	31 08	199	41 09	256	60 46	295
119	54 41	036	50 03	125	55 04	188	30 52	200	40 25	257	60 04	295
	Dubhe		REGULUS		PROCYON		BETELGEUSE		ALDEBARAN		CAPELLA	
120	55 08	036	50 40	126	54 57	190	46 47	230	39 40	258	59 22	295
121	55 35	036	51 17	127	54 48	192	46 12	231	38 55	258	58 41	295
122	56 02	035	51 53	129	54 39	193	45 36	232	38 10	259	57 59	295
123	56 28	035	52 29	130	54 27	195	44 59	233	37 25	260	57 18	295
124	56 54	035	53 04	131	54 15	197	44 22	234	36 39	261	56 36	296
125	57 20	034	53 38	133	54 01	198	43 45	235	35 54	261	55 55	296
126	57 46	034	54 12	134	53 46	200	43 07	236	35 08	262	55 13	296
127	58 12	034	54 44	135	53 30	202	42 28	237	34 23	263	54 32	296
128	58 37	033	55 16	137	53 12	203	41 50	238	33 37	263	53 51	296
129	59 02	033	55 47	138	52 53	205	41 10	239	32 52	264	53 10	296
130	59 27	032	56 18	140	52 34	206	40 31	240	32 06	265	52 28	297
131	59 51	032	56 47	141	52 13	208	39 50	241	31 20	265	51 47	297
132	60 15	031	57 15	143	51 51	209	39 10	242	30 34	266	51 06	297
133	60 39	031	57 42	144	51 28	211	38 29	243	29 48	267	50 26	297
134	61 02	030	58 09	146	51 04	212	37 48	244	29 02	268	49 45	297
	Kochab		ARCTURUS		REGULUS		PROCYON		BETELGEUSE		CAPELLA	
135	38 51	020	20 59	082	58 34	148	50 39	214	37 06	245	49 04	298
136	39 06	020	21 44	082	58 58	149	50 13	215	36 25	246	48 23	298
137	39 22	020	22 30	083	59 21	151	49 46	216	35 43	247	47 43	298
138	39 39	020	23 15	084	59 42	153	49 18	218	35 00	248	47 02	298
139	39 55	021	24 01	084	60 02	155	48 49	219	34 18	248	46 22	299
140	40 11	021	24 47	085	60 21	157	48 20	220	33 35	249	45 42	299
141	40 27	021	25 33	085	60 39	159	47 50	222	32 52	250	45 01	299
142	40 43	021	26 18	086	60 55	160	47 19	223	32 08	251	44 21	299
143	40 59	021	27 04	087	61 09	162	46 47	224	31 25	252	43 41	300
144	41 15	021	27 50	087	61 22	164	46 14	225	30 41	252	43 02	300
145	41 32	021	28 36	088	61 34	166	45 41	227	29 57	253	42 22	300
146	41 48	021	29 22	089	61 44	168	45 08	228	29 13	254	41 42	301
147	42 04	021	30 08	089	61 52	171	44 33	229	28 29	255	41 03	301
148	42 20	021	30 54	090	61 59	173	43 58	230	27 45	255	40 23	301
149	42 36	021	31 40	090	62 04	175	43 23	231	27 00	256	39 44	302
	Kochab		ARCTURUS		SPICA		REGULUS		PROCYON		CAPELLA	
150	42 53	021	32 26	091	20 42	126	62 08	177	42 46	232	39 05	302
151	43 09	021	33 12	092	21 19	126	62 10	179	42 10	233	38 26	302
152	43 25	021	33 58	092	21 56	127	62 10	181	41 33	234	37 47	302
153	43 41	021	34 44	093	22 32	128	62 08	183	40 55	235	37 08	303
154	43 57	020	35 30	094	23 08	129	62 05	185	40 17	236	36 30	303
155	44 13	020	36 15	094	23 44	130	62 00	187	39 38	237	35 51	303
156	44 29	020	37 01	095	24 19	131	61 53	189	38 59	238	35 13	304
157	44 45	020	37 47	096	24 54	132	61 45	191	38 20	239	34 35	304
158	45 01	020	38 33	097	25 28	132	61 35	193	37 40	240	33 57	304
159	45 17	020	39 18	097	26 02	133	61 24	195	37 00	241	33 19	305
160	45 33	020	40 04	098	26 35	134	61 11	197	36 20	242	32 42	305
161	45 49	020	40 49	099	27 07	135	60 57	199	35 39	243	32 04	306
162	46 04	020	41 35	100	27 40	136	60 41	201	34 58	244	31 27	306
163	46 20	020	42 20	100	28 11	137	60 23	203	34 16	245	30 50	306
164	46 35	020	43 05	101	28 42	138	60 05	205	33 35	246	30 13	307
	Kochab		ARCTURUS		SPICA		REGULUS		POLLUX		CAPELLA	
165	46 51	020	43 50	102	29 13	139	59 45	207	48 03	269	29 36	307
166	47 06	019	44 35	103	29 43	140	59 23	209	47 17	270	28 59	307
167	47 21	019	45 20	103	30 12	141	59 01	210	46 31	271	28 23	308
168	47 36	019	46 04	104	30 41	142	58 37	212	45 45	271	27 47	308
169	47 51	019	46 49	105	31 09	143	58 12	214	44 59	272	27 11	309
170	48 06	019	47 33	106	31 36	144	57 46	215	44 13	272	26 35	309
171	48 21	019	48 17	107	32 03	145	57 19	217	43 27	273	25 59	309
172	48 35	018	49 01	108	32 29	146	56 50	219	42 41	274	25 24	310
173	48 50	018	49 45	109	32 55	147	56 21	220	41 56	274	24 49	310
174	49 04	018	50 28	110	33 19	148	55 51	222	41 10	275	24 14	311
175	49 18	018	51 11	111	33 43	149	55 20	223	40 24	275	23 39	311
176	49 32	018	51 54	112	34 06	150	54 48	225	39 38	276	23 05	311
177	49 46	017	52 37	113	34 29	151	54 16	226	38 52	277	22 30	312
178	50 00	017	53 19	114	34 51	152	53 42	227	38 07	277	21 56	312
179	50 13	017	54 01	115	35 12	154	53 08	229	37 21	278	21 22	313

Appendix I-2

LAT 40°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	VEGA		ARCTURUS		SPICA		REGULUS		POLLUX		CAPELLA	
180	18 03	054	54 43	116	35 32	155	52 33	230	36 36	278	20 49	313
181	18 41	055	55 24	117	35 51	156	51 58	231	35 50	279	20 15	314
182	19 18	055	56 05	118	36 09	157	51 22	232	35 05	279	19 42	314
183	19 56	056	56 45	119	36 27	158	50 45	234	34 20	280	19 09	315
184	20 34	056	57 25	121	36 43	159	50 07	235	33 34	280	18 37	315
185	21 12	057	58 04	122	36 59	160	49 30	236	32 49	281	18 04	316
186	21 51	057	58 43	123	37 14	162	48 51	237	32 04	282	17 32	316
187	22 29	058	59 21	124	37 28	163	48 12	238	31 19	282	17 00	316
188	23 08	058	59 59	126	37 41	164	47 33	239	30 34	283	16 29	317
189	23 47	058	60 36	127	37 53	165	46 53	240	29 49	283	15 58	317
190	24 27	059	61 12	129	38 05	167	46 13	241	29 05	284	15 27	318
191	25 06	059	61 47	130	38 15	168	45 33	242	28 20	284	14 56	318
192	25 46	060	62 22	132	38 24	169	44 52	243	27 36	285	14 26	319
193	26 26	060	62 56	134	38 32	170	44 10	244	26 51	285	13 56	319
194	27 06	061	63 28	135	38 40	171	43 29	245	26 07	286	13 26	320
	VEGA		ARCTURUS		SPICA		REGULUS		POLLUX		Dubhe	
195	27 46	061	64 00	137	38 46	173	42 47	246	25 23	286	61 40	331
196	28 26	062	64 31	139	38 51	174	42 05	247	24 39	287	61 17	330
197	29 07	062	65 01	141	38 56	175	41 22	248	23 55	288	60 54	330
198	29 47	063	65 29	143	38 59	177	40 39	249	23 11	288	60 30	329
199	30 28	063	65 56	145	39 01	178	39 56	250	22 28	289	60 06	328
200	31 09	063	66 22	147	39 03	179	39 13	251	21 44	289	59 42	328
201	31 51	064	66 47	149	39 03	180	38 29	252	21 01	290	59 18	328
202	32 32	064	67 10	151	39 02	182	37 46	252	20 18	290	58 53	327
203	33 13	065	67 31	153	39 00	183	37 02	253	19 34	291	58 28	327
204	33 55	065	67 51	156	38 58	184	36 18	254	18 52	291	58 02	326
205	34 37	066	68 09	158	38 54	185	35 33	255	18 09	292	57 37	326
206	35 19	066	68 25	161	38 49	187	34 49	256	17 26	292	57 11	326
207	36 01	066	68 39	163	38 43	188	34 04	256	16 44	293	56 45	325
208	36 43	067	68 52	166	38 36	189	33 20	257	16 02	294	56 19	325
209	37 25	067	69 02	168	38 29	190	32 35	258	15 20	294	55 52	325
	DENEB		VEGA		ARCTURUS		SPICA		REGULUS		Dubhe	
210	21 12	048	38 08	068	69 11	171	38 20	192	31 50	259	55 25	324
211	21 46	049	38 50	068	69 17	173	38 10	193	31 05	259	54 59	324
212	22 21	049	39 33	068	69 21	176	38 00	194	30 19	260	54 32	324
213	22 56	049	40 16	069	69 23	179	37 48	195	29 34	261	54 04	324
214	23 31	050	40 59	069	69 23	181	37 35	196	28 49	262	53 37	323
215	24 06	050	41 42	070	69 21	184	37 22	198	28 03	262	53 10	323
216	24 42	051	42 25	070	69 16	187	37 07	199	27 18	263	52 42	323
217	25 17	051	43 08	071	69 10	189	36 52	200	26 32	264	52 15	323
218	25 53	052	43 52	071	69 01	192	36 36	201	25 46	264	51 47	323
219	26 29	052	44 35	071	68 51	195	36 19	202	25 00	265	51 19	323
220	27 06	052	45 19	072	68 38	197	36 01	204	24 15	266	50 51	323
221	27 42	053	46 02	072	68 24	200	35 42	205	23 29	266	50 23	322
222	28 19	053	46 46	073	68 07	202	35 22	206	22 43	267	49 55	322
223	28 56	054	47 30	073	67 49	204	35 02	207	21 57	268	49 27	322
224	29 33	054	48 14	073	67 29	207	34 41	208	21 11	268	48 59	322
	DENEB		VEGA		ALTAIR		ANTARES		ARCTURUS		Dubhe	
225	30 10	054	48 58	074	19 13	095	20 38	159	67 08	209	48 31	322
226	30 48	055	49 42	074	19 59	095	20 54	160	66 45	211	48 03	322
227	31 25	055	50 27	075	20 45	096	21 09	161	66 20	213	47 35	322
228	32 03	056	51 11	075	21 31	097	21 24	162	65 54	215	47 06	322
229	32 41	056	51 55	075	22 16	097	21 38	163	65 27	217	46 38	322
230	33 19	056	52 40	076	23 02	098	21 51	164	64 58	219	46 10	322
231	33 57	057	53 24	076	23 47	099	22 03	165	64 29	221	45 42	322
232	34 36	057	54 09	076	24 33	099	22 15	166	63 58	223	45 14	322
233	35 14	057	54 54	077	25 18	100	22 26	167	63 26	225	44 45	322
234	35 53	058	55 39	077	26 03	101	22 36	168	62 53	227	44 17	322
235	36 32	058	56 23	078	26 48	102	22 46	169	62 19	228	43 49	322
236	37 11	058	57 08	078	27 33	102	22 54	170	61 44	230	43 21	322
237	37 50	059	57 53	078	28 18	103	23 02	171	61 09	231	42 53	322
238	38 30	059	58 38	079	29 03	104	23 09	171	60 33	233	42 25	323
239	39 09	059	59 24	079	29 47	105	23 16	172	59 56	234	41 57	323
	DENEB		VEGA		ALTAIR		ANTARES		ARCTURUS		Dubhe	
240	39 49	060	60 09	080	30 32	105	23 22	173	59 18	236	41 29	323
241	40 28	060	60 54	080	31 16	106	23 26	174	58 40	237	41 02	323
242	41 08	060	61 39	080	32 00	107	23 31	175	58 01	238	40 34	323
243	41 48	061	62 25	081	32 44	108	23 34	176	57 22	240	40 06	323
244	42 28	061	63 10	081	33 28	108	23 36	177	56 42	241	39 39	323
245	43 09	061	63 56	082	34 11	109	23 38	178	56 01	242	39 11	323
246	43 49	061	64 41	082	34 54	110	23 39	179	55 20	243	38 44	324
247	44 29	062	65 27	083	35 37	111	23 39	180	54 39	244	38 17	324
248	45 10	062	66 12	083	36 20	112	23 39	181	53 58	245	37 49	324
249	45 51	062	66 58	083	37 03	113	23 37	182	53 16	246	37 22	324
250	46 31	063	67 44	084	37 45	113	23 35	183	52 33	247	36 55	324
251	47 12	063	68 29	084	38 27	114	23 32	184	51 51	248	36 29	324
252	47 53	063	69 15	085	39 09	115	23 26	185	51 08	249	36 02	325
253	**48 34**	**063**	**70 01**	**085**	**39 50**	**116**	**23 24**	**186**	**50 25**	**250**	**35 35**	**325**
254	**49 15**	**064**	**70 47**	**086**	**40 31**	**117**	**23 19**	**187**	**49 41**	**251**	**35 09**	**325**
	DENEB		ALTAIR		Nunki		ANTARES		ARCTURUS		Dubhe	
255	49 57	064	41 12	118	18 39	153	23 13	188	48 58	252	34 42	325
256	50 38	064	41 52	119	18 59	154	23 06	189	48 14	253	34 16	325
257	51 19	064	42 32	120	19 19	155	22 58	190	47 30	254	33 50	326
258	52 01	065	43 12	121	19 38	156	22 50	191	46 45	255	33 24	326
259	52 42	065	43 51	122	19 56	157	22 41	192	46 01	256	32 58	326
260	53 24	065	44 30	123	20 13	158	22 31	193	45 16	257	32 33	326
261	54 06	065	45 08	124	20 30	159	22 20	194	44 31	257	32 07	326
262	54 48	065	45 46	125	20 47	160	22 09	195	43 46	258	31 42	327
263	55 29	066	46 23	126	21 02	161	21 57	196	43 01	259	31 17	327
264	56 11	066	47 00	127	21 17	162	21 44	197	42 16	260	30 52	327
265	56 53	066	47 36	129	21 31	162	21 31	198	41 31	261	30 27	327
266	57 35	066	48 12	130	21 45	163	21 16	198	40 46	261	30 03	328
267	58 17	066	48 47	131	21 58	164	21 01	199	40 00	262	29 38	328
268	58 59	066	49 21	132	22 10	165	20 46	200	39 15	263	29 14	328
269	59 42	067	49 55	133	22 21	166	20 29	201	38 29	263	28 50	329

LAT 40°N

LHA T	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	DENEB		ALTAIR		Nunki		Rasalhague		ARCTURUS		Kochab	
270	60 24	067	50 28	135	22 31	167	61 57	194	37 43	264	49 24	342
271	61 06	067	51 00	136	22 41	168	61 45	196	36 57	265	49 10	342
272	61 48	067	51 32	137	22 50	169	61 32	198	36 12	266	48 56	342
273	62 30	067	52 02	139	22 59	170	61 17	200	35 26	266	48 41	342
274	63 13	067	52 32	140	23 06	171	61 00	202	34 40	267	48 27	341
275	63 55	067	53 01	142	23 13	172	60 42	204	33 54	268	48 12	341
276	64 37	067	53 29	143	23 19	173	60 23	206	33 08	268	47 57	341
277	65 20	067	53 56	145	23 24	174	60 02	208	32 22	269	47 42	341
278	66 02	067	54 23	146	23 29	175	59 40	209	31 36	270	47 27	341
279	66 44	067	54 48	148	23 32	176	59 17	211	30 50	270	47 12	341
280	67 27	067	55 12	149	23 35	177	58 53	213	30 04	271	46 57	341
281	68 09	067	55 35	151	23 37	178	58 27	215	29 18	271	46 41	340
282	68 51	067	55 57	152	23 39	179	58 00	216	28 32	272	46 26	340
283	69 33	067	56 17	154	23 39	180	57 33	218	27 46	273	46 10	340
284	70 16	066	56 37	156	23 39	181	57 04	219	27 01	273	45 55	340
	DENEB		Alpheratz		ALTAIR		Rasalhague		ARCTURUS		Kochab	
285	70 58	066	27 47	074	56 55	157	56 34	221	26 15	274	45 39	340
286	71 40	066	28 31	075	57 12	159	56 04	222	25 29	275	45 23	340
287	72 21	066	29 15	075	57 28	161	55 32	224	24 43	275	45 08	340
288	73 03	065	30 00	076	57 42	163	55 00	225	23 57	276	44 52	340
289	73 45	065	30 45	076	57 55	165	54 27	227	23 12	276	44 36	340
290	74 26	064	31 29	077	58 06	166	53 53	228	22 26	277	44 20	340
291	75 08	064	32 14	078	58 16	168	53 18	229	21 40	278	44 04	340
292	75 49	063	32 59	078	58 25	170	52 43	231	20 55	278	43 48	339
293	76 29	062	33 44	079	58 32	172	52 07	232	20 09	279	43 31	339
294	77 10	061	34 29	079	58 38	174	51 31	233	19 24	279	43 15	339
295	77 50	060	35 14	080	58 42	176	50 54	234	18 39	280	42 59	339
296	78 29	059	36 00	080	58 45	178	50 16	236	17 53	281	42 43	339
297	79 09	058	36 45	081	58 46	180	49 38	237	17 08	281	42 27	339
298	79 47	056	37 30	081	58 45	182	48 59	238	16 23	282	42 11	339
299	80 25	054	38 16	082	58 43	183	48 20	239	15 38	282	41 54	339
	Schedar		Alpheratz		ALTAIR		Rasalhague		VEGA		Kochab	
300	43 06	045	39 01	082	58 40	185	47 40	240	73 41	272	41 38	339
301	43 39	046	39 47	083	58 35	187	47 00	241	72 55	273	41 22	339
302	44 12	046	40 33	084	58 28	189	46 20	242	72 09	273	41 06	339
303	44 44	046	41 18	084	58 20	191	45 39	243	71 23	274	40 49	339
304	45 17	046	42 04	085	58 11	193	44 58	244	70 37	274	40 33	339
305	45 50	046	42 50	085	58 00	195	44 16	245	69 51	275	40 17	339
306	46 24	046	43 36	086	57 48	196	43 34	246	69 05	275	40 01	339
307	46 57	046	44 22	087	57 34	198	42 52	247	68 20	276	39 45	340
308	47 30	046	45 07	087	57 19	200	42 10	248	67 34	276	39 29	340
309	48 03	046	45 53	088	57 02	202	41 27	249	66 48	277	39 13	340
310	48 36	046	46 39	088	56 45	204	40 44	250	66 03	277	38 57	340
311	49 09	046	47 25	089	56 26	205	40 01	251	65 17	278	38 41	340
312	49 43	046	48 11	090	56 05	207	39 17	251	64 32	278	38 25	340
313	50 16	046	48 57	090	55 44	209	38 34	252	63 46	278	38 09	340
314	50 49	046	49 43	091	55 22	210	37 50	253	63 01	279	37 53	340
	Schedar		Alpheratz		FOMALHAUT		ALTAIR		VEGA		Kochab	
315	51 23	046	50 29	092	15 12	154	54 58	212	62 15	279	37 38	340
316	51 56	046	51 15	092	15 32	155	54 33	213	61 30	280	37 22	340
317	52 29	046	52 01	093	15 51	156	54 07	215	60 45	280	37 07	340
318	53 02	046	52 47	094	16 09	157	53 41	216	59 59	280	36 51	340
319	53 35	046	53 33	094	16 27	158	53 13	218	59 14	281	36 36	340
320	54 09	046	54 19	095	16 44	159	52 44	219	58 29	281	36 20	341
321	54 42	046	55 04	096	17 01	159	52 15	221	57 44	282	36 05	341
322	55 15	046	55 50	097	17 16	160	51 45	222	56 59	282	35 50	341
323	55 48	046	56 36	097	17 32	161	51 13	223	56 14	282	35 35	341
324	56 21	046	57 21	098	17 46	162	50 41	225	55 29	283	35 20	341
325	56 53	045	58 07	099	18 00	163	50 09	226	54 44	283	35 05	341
326	57 26	045	58 52	100	18 13	164	49 35	227	54 00	284	34 50	341
327	57 59	045	59 37	101	18 26	165	49 01	228	53 15	284	34 35	341
328	58 31	045	60 22	102	18 38	166	48 27	230	52 31	284	34 21	342
329	59 03	045	61 07	102	18 49	166	47 51	231	51 46	285	34 06	342
	CAPELLA		Alpheratz		FOMALHAUT		ALTAIR		VEGA		Kochab	
330	17 05	044	61 52	103	18 59	167	47 15	232	51 02	285	33 52	342
331	17 37	044	62 37	104	19 09	168	46 39	233	50 17	286	33 38	342
332	18 09	045	63 21	105	19 18	169	45 02	234	49 33	286	33 24	342
333	18 41	045	64 05	107	19 26	170	45 24	235	48 49	286	33 10	342
334	19 14	045	64 49	108	19 34	171	44 46	236	48 05	287	32 56	343
335	19 47	046	65 33	109	19 41	172	44 07	238	47 21	287	32 42	343
336	20 20	046	66 16	110	19 47	173	43 28	239	46 37	288	32 29	343
337	20 53	047	66 59	111	19 53	174	42 49	240	45 53	288	32 15	343
338	21 27	047	67 42	113	19 57	175	42 09	241	45 10	288	32 02	343
339	22 01	048	68 24	114	20 01	176	41 29	242	44 26	289	31 49	343
340	22 35	048	69 06	115	20 04	176	40 48	243	43 43	289	31 36	344
341	23 09	049	69 47	117	20 07	177	40 07	243	42 59	290	31 23	344
342	23 44	049	70 28	119	20 09	178	39 26	244	42 16	290	31 10	344
343	**24 19**	**049**	**71 08**	**120**	**20 10**	**179**	**38 45**	**245**	**41 33**	**290**	**30 57**	**344**
344	**24 54**	**050**	**71 47**	**122**	**20 10**	**180**	**38 03**	**246**	**40 50**	**291**	**30 45**	**344**
	CAPELLA		ALDEBARAN		FOMALHAUT		ALTAIR		VEGA		Kochab	
345	25 29	050	15 26	081	20 09	181	37 20	247	40 07	291	30 33	345
346	26 04	051	16 12	082	20 08	182	36 38	248	39 24	292	30 21	345
347	26 40	051	16 57	083	20 06	183	35 55	249	38 41	292	30 09	345
348	27 16	051	17 43	083	20 04	184	35 12	250	37 59	292	29 57	345
349	27 52	052	18 29	084	20 00	185	34 29	250	37 16	293	29 45	345
350	28 28	052	19 14	084	19 56	186	33 46	251	36 34	293	29 34	345
351	29 04	053	20 00	085	19 51	187	33 02	252	35 52	294	29 23	346
352	29 41	053	20 46	086	19 45	187	32 18	253	35 10	294	29 11	346
353	30 18	053	21 32	086	19 39	188	31 34	254	34 28	295	29 01	346
354	30 55	054	22 18	087	19 32	189	30 50	254	33 46	295	28 50	347
355	31 32	054	23 03	087	19 24	190	30 06	255	33 05	295	28 39	347
356	32 09	054	23 49	088	19 16	191	29 21	256	32 23	296	28 29	347
357	32 47	055	24 35	089	19 06	192	28 37	257	31 42	296	28 19	347
358	33 24	055	25 21	089	18 56	193	27 52	257	31 01	297	28 09	348
359	34 02	056	26 07	090	18 46	194	27 07	258	30 20	297	27 59	348

65°, 295° L.H.A. LATITUDE SAME NAME AS DECLINATION N. Lat. {L.H.A. greater than 180°......Zn=Z; L.H.A. less than 180°............Zn=360°−Z}

Dec.	30° Hc	d	Z	31° Hc	d	Z	32° Hc	d	Z	33° Hc	d	Z	34° Hc	d	Z	35° Hc	d	Z	36° Hc	d	Z	37° Hc	d	Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	21 28.1	+32.1	103.1	21 14.3	+33.0	103.5	21 00.1	+33.9	103.9	20 45.5	+34.9	104.3	20 30.6	+35.7	104.6	20 15.3	+36.5	105.0	19 59.6	+37.4	105.3	19 43.5	+38.3	105.7	0
1	22 00.2	31.8	102.2	21 47.3	32.8	102.6	21 34.0	33.7	103.0	21 20.4	34.5	103.4	21 06.3	35.0	103.8	20 51.8	36.3	104.1	20 37.0	37.2	104.5	20 21.8	38.0	104.9	1
2	22 32.0	31.5	101.3	22 20.1	32.4	101.7	22 07.7	33.3	102.1	21 54.9	34.3	102.5	21 41.7	35.2	102.9	21 28.1	36.1	103.3	21 14.2	36.9	103.7	20 59.8	37.8	104.0	2
3	23 03.5	31.1	100.4	22 52.5	32.1	100.8	22 41.0	33.1	101.2	22 29.2	33.9	101.6	22 16.9	34.8	102.0	22 04.2	35.8	102.4	21 51.1	36.6	102.8	21 37.6	37.5	103.2	3
4	23 34.6	30.8	99.4	23 24.5	31.7	99.9	23 14.1	32.7	100.3	23 03.1	33.7	100.7	22 51.7	34.6	101.1	22 40.0	35.4	101.5	22 27.7	36.4	102.0	22 15.1	37.3	102.4	4
5	24 05.4	+30.5	98.5	23 56.3	+31.5	98.9	23 46.8	+32.4	99.4	23 36.8	+33.3	99.8	23 26.3	+34.3	100.2	23 15.4	+35.2	100.7	23 04.1	+36.1	101.1	22 52.4	+37.0	101.5	5
6	24 35.9	30.1	97.6	24 27.8	31.1	98.0	24 19.2	32.0	98.5	24 10.1	33.0	98.9	24 00.6	34.0	99.3	23 50.6	34.9	99.8	23 40.2	35.8	100.2	23 29.4	36.7	100.6	6
7	25 06.0	29.8	96.6	24 58.9	30.7	97.1	24 51.2	31.8	97.5	24 43.1	32.7	98.0	24 34.6	33.6	98.4	24 25.5	34.6	98.9	24 16.0	35.5	99.3	24 06.1	36.4	99.8	7
8	25 35.8	29.3	95.6	25 29.6	30.4	96.1	25 23.0	31.3	96.6	25 15.8	32.4	97.1	25 08.2	33.3	97.5	25 00.1	34.3	98.0	24 51.5	35.2	98.5	24 42.5	36.1	98.9	8
9	26 05.1	29.0	94.7	26 00.0	30.0	95.2	25 54.3	31.0	95.6	25 48.2	31.9	96.1	25 41.5	33.0	96.6	25 34.4	33.9	97.1	25 26.7	34.9	97.6	25 18.6	35.8	98.0	9
10	26 34.1	+28.6	93.7	26 30.0	+29.5	94.2	26 25.3	+30.6	94.7	26 20.1	+31.6	95.2	26 14.5	+32.5	95.7	26 08.3	+33.5	96.2	26 01.6	+34.5	96.7	25 54.4	+35.4	97.1	10
11	27 02.7	28.1	92.7	26 59.5	29.2	93.2	26 55.9	30.2	93.7	26 51.7	31.3	94.2	26 47.0	32.3	94.7	26 41.8	33.2	95.2	26 36.1	34.1	95.7	26 29.8	35.1	96.2	11
12	27 30.8	27.7	91.7	27 28.7	28.8	92.2	27 26.1	29.8	92.8	27 23.0	30.8	93.3	27 19.3	31.8	93.8	27 15.0	32.8	94.3	27 10.2	33.8	94.8	27 04.9	34.8	95.3	12
13	27 58.5	27.3	90.7	27 57.5	28.3	91.2	27 55.9	29.4	91.8	27 53.8	30.4	92.3	27 51.1	31.4	92.8	27 47.8	32.5	93.4	27 44.0	33.5	93.9	27 39.7	34.4	94.4	13
14	28 25.8	26.8	89.7	28 25.8	27.9	90.2	28 25.3	28.9	90.8	28 24.2	30.0	91.3	28 22.5	31.0	91.9	28 20.3	32.0	92.4	28 17.5	33.0	92.9	28 14.1	34.0	93.5	14
15	28 52.6	+26.4	88.7	28 53.7	+27.5	89.2	28 54.2	+28.5	89.8	28 54.2	+29.5	90.3	28 53.5	+30.6	90.9	28 52.3	+31.6	91.4	28 50.5	+32.6	92.0	28 48.1	+33.6	92.5	15
16	29 19.0	25.9	87.7	29 21.2	26.9	88.2	29 22.7	28.1	88.8	29 23.7	29.1	89.3	29 24.1	30.1	89.9	29 23.9	31.2	90.5	29 23.1	32.2	91.0	29 21.7	33.2	91.6	16
17	29 44.9	25.4	86.6	29 48.1	26.5	87.2	29 50.8	27.5	87.8	29 52.8	28.6	88.3	29 54.2	29.7	88.9	29 55.1	30.7	89.5	29 55.3	31.8	90.1	29 54.9	32.8	90.6	17
18	30 10.3	24.9	85.6	30 14.6	26.0	86.2	30 18.3	27.1	86.7	30 21.4	28.2	87.3	30 23.9	29.3	87.9	30 25.8	30.3	88.5	30 27.1	31.3	89.1	30 27.7	32.4	89.7	18
19	30 35.2	24.4	84.5	30 40.6	25.5	85.1	30 45.4	26.6	85.7	30 49.6	27.7	86.3	30 53.2	28.7	86.9	30 56.1	29.8	87.5	30 58.4	30.9	88.1	31 00.1	31.9	88.7	19
20	30 59.6	+23.8	83.5	31 06.1	+25.0	84.1	31 12.0	+26.1	84.7	31 17.3	+27.1	85.3	31 21.9	+28.3	85.9	31 25.9	+29.3	86.5	31 29.3	+30.4	87.1	31 32.0	+31.5	87.7	20
21	31 23.4	23.4	82.4	31 31.1	24.4	83.0	31 38.1	25.5	83.6	31 44.4	26.7	84.2	31 50.2	27.7	84.8	31 55.2	28.9	85.5	31 59.7	29.9	86.1	32 03.5	30.9	86.7	21
22	31 46.8	22.7	81.3	31 55.5	23.9	81.9	32 03.6	25.0	82.5	32 11.1	26.1	83.2	32 17.9	27.2	83.8	32 24.1	28.3	84.4	32 29.6	29.4	85.1	32 34.4	30.5	85.7	22
23	32 09.5	22.2	80.2	32 19.4	23.3	80.8	32 28.6	24.5	81.5	32 37.2	25.6	82.1	32 45.1	26.7	82.7	32 52.4	27.8	83.4	32 59.0	28.9	84.0	33 04.9	30.0	84.7	23
24	32 31.7	21.7	79.1	32 42.7	22.8	79.7	32 53.1	23.9	80.4	33 02.8	25.0	81.0	33 11.8	26.2	81.7	33 20.2	27.2	82.3	33 27.9	28.3	83.0	33 34.9	29.4	83.6	24
25	32 53.4	+21.0	78.0	33 05.5	+22.2	78.6	33 17.0	+23.3	79.3	33 27.8	+24.4	79.9	33 38.0	+25.5	80.6	33 47.4	+26.7	81.2	33 56.2	+27.8	81.9	34 04.3	+28.9	82.6	25
26	33 14.4	20.4	76.9	33 27.7	21.5	77.5	33 40.3	22.7	78.2	33 52.2	23.9	78.8	34 03.5	25.0	79.5	34 14.1	26.1	80.2	34 24.0	27.2	80.8	34 33.2	28.4	81.5	26
27	33 34.8	19.8	75.8	33 49.2	21.0	76.4	34 03.0	22.1	77.1	34 16.1	23.2	77.7	34 28.5	24.4	78.4	34 40.2	25.5	79.1	34 51.2	26.7	79.8	35 01.6	27.7	80.4	27
28	33 54.6	19.2	74.6	34 10.2	20.3	75.3	34 25.1	21.5	75.9	34 39.3	22.7	76.6	34 52.9	23.8	77.3	35 05.7	25.0	78.0	35 17.9	26.0	78.7	35 29.3	27.2	79.4	28
29	34 13.8	18.5	73.5	34 30.5	19.7	74.1	34 46.6	20.8	74.8	35 02.0	22.0	75.5	35 16.7	23.1	76.2	35 30.7	24.3	76.9	35 43.9	25.5	77.6	35 56.5	26.6	78.3	29
30	34 32.3	+17.9	72.3	34 50.2	+19.0	73.0	35 07.4	+20.2	73.7	35 24.0	+21.3	74.3	35 39.8	+22.5	75.0	35 55.0	+23.6	75.7	36 09.4	+24.8	76.4	36 23.1	+25.9	77.1	30
31	34 50.2	17.2	71.2	35 09.2	18.4	71.8	35 27.6	19.5	72.5	35 45.3	20.7	73.2	36 02.3	21.9	73.9	36 18.6	23.0	74.6	36 34.2	24.1	75.3	36 49.0	25.4	76.0	31
32	35 07.4	16.6	70.0	35 27.6	17.7	70.7	35 47.1	18.9	71.3	36 06.0	20.0	72.0	36 24.2	21.1	72.7	36 41.6	22.3	73.4	36 58.3	23.5	74.2	37 14.4	24.6	74.9	32
33	35 24.0	15.8	68.8	35 45.3	17.0	69.5	36 06.0	18.2	70.2	36 26.0	19.3	70.9	36 45.3	20.5	71.6	37 03.9	21.7	72.3	37 21.8	22.9	73.0	37 39.0	24.0	73.7	33
34	35 39.8	15.2	67.6	36 02.3	16.3	68.3	36 24.2	17.4	69.0	36 45.3	18.6	69.7	37 05.8	19.8	70.4	37 25.6	20.9	71.1	37 44.7	22.1	71.8	38 03.0	23.3	72.6	34
35	35 55.0	+14.4	66.4	36 18.6	+15.6	67.1	36 41.6	+16.7	67.8	37 03.9	+17.9	68.5	37 25.6	+19.1	69.2	37 46.5	+20.3	69.9	38 06.8	+21.4	70.7	38 26.3	+22.5	71.4	35
36	36 09.4	13.7	65.2	36 34.2	14.8	65.9	36 58.3	16.1	66.6	37 21.8	17.2	67.3	37 44.7	18.3	68.0	38 06.8	19.5	68.7	38 28.2	20.6	69.5	38 48.8	21.9	70.2	36
37	36 23.1	13.0	64.0	36 49.0	14.2	64.7	37 14.4	15.2	65.4	37 39.0	16.4	66.1	38 03.0	17.6	66.8	38 26.3	18.7	67.5	38 48.8	20.0	68.3	39 10.7	21.1	69.0	37
38	36 36.1	12.2	62.8	37 03.2	13.3	63.5	37 29.6	14.5	64.2	37 55.4	15.7	64.9	38 20.6	16.8	65.6	38 45.0	18.0	66.3	39 08.8	19.1	67.1	39 31.8	20.3	67.8	38
39	36 48.3	11.5	61.6	37 16.5	12.6	62.3	37 44.1	13.8	63.0	38 11.1	14.9	63.6	38 37.4	16.0	64.4	39 03.0	17.2	65.1	39 27.9	18.4	65.8	39 52.1	19.6	66.6	39
40	36 59.8	+10.7	60.4	37 29.1	+11.9	61.0	37 57.9	+13.0	61.7	38 26.0	+14.1	62.4	38 53.4	+15.3	63.1	39 20.2	+16.5	63.9	39 46.3	+17.6	64.6	40 11.7	+18.8	65.4	40
41	37 10.5	9.9	59.1	37 41.0	11.0	59.8	38 10.9	12.1	60.5	38 40.1	13.3	61.2	39 08.7	14.5	61.9	39 36.7	15.6	62.6	40 03.9	16.8	63.3	40 30.5	17.9	64.1	41
42	37 20.4	9.2	57.9	37 52.0	10.3	58.6	38 23.0	11.4	59.2	38 53.4	12.5	59.9	39 23.2	13.6	60.6	39 52.3	14.8	61.3	40 20.7	16.0	62.1	40 48.4	17.2	62.9	42
43	37 29.6	8.4	56.7	38 02.3	9.5	57.3	38 34.4	10.6	58.0	39 05.9	11.7	58.7	39 36.8	12.9	59.4	40 07.1	14.0	60.1	40 36.7	15.1	60.8	41 05.6	16.3	61.6	43
44	37 38.0	7.6	55.4	38 11.8	8.7	56.1	38 45.0	9.8	56.7	39 17.6	10.9	57.4	39 49.7	12.0	58.1	40 21.1	13.1	58.8	40 51.8	14.3	59.5	41 21.9	15.4	60.3	44
45	37 45.6	+6.8	54.2	38 20.5	+7.8	54.8	38 54.8	+8.9	55.4	39 28.5	+10.0	56.1	40 01.7	+11.1	56.8	40 34.2	+12.2	57.5	41 06.1	+13.4	58.3	41 37.3	+14.6	59.0	45
46	37 52.4	6.0	52.9	38 28.3	7.1	53.5	39 03.7	8.1	54.2	39 38.5	9.2	54.8	40 12.8	10.3	55.5	40 46.4	11.5	56.2	41 19.5	12.5	57.0	41 51.9	13.6	57.7	46
47	37 58.4	5.1	51.6	38 35.4	6.2	52.3	39 11.8	7.3	52.9	39 47.7	8.4	53.6	40 23.1	9.4	54.2	40 57.9	10.5	54.9	41 32.0	11.7	55.7	42 05.5	12.8	56.4	47
48	38 03.5	4.4	50.4	38 41.6	5.3	51.0	39 19.1	6.4	51.6	39 56.1	7.4	52.3	40 32.5	8.6	52.9	41 08.4	9.6	53.6	41 43.7	10.7	54.3	42 18.3	11.9	55.1	48
49	38 07.9	3.5	49.1	38 46.9	4.6	49.7	39 25.5	5.6	50.3	40 03.5	6.6	51.0	40 41.1	7.6	51.6	41 18.0	8.7	52.3	41 54.4	9.8	53.0	42 30.2	10.9	53.8	49
50	38 11.4	+2.8	47.8	38 51.5	+3.7	48.4	39 31.1	+4.7	49.0	40 10.1	+5.8	49.7	40 48.7	+6.8	50.3	41 26.7	+7.9	51.0	42 04.2	+8.9	51.7	42 41.1	+10.0	52.4	50
51	38 14.2	1.9	46.6	38 55.2	2.9	47.1	39 35.8	3.8	47.7	40 15.9	4.8	48.4	40 55.5	5.9	49.0	41 34.6	6.9	49.7	42 13.1	8.0	50.4	42 51.1	9.1	51.1	51
52	38 16.1	1.0	45.3	38 58.1	2.0	45.9	39 39.6	3.0	46.5	40 20.7	4.0	47.1	41 01.4	4.9	47.7	41 41.5	6.0	48.4	42 21.1	7.0	49.0	43 00.2	8.1	49.7	52
53	38 17.1	+0.3	44.0	39 00.1	1.1	44.6	39 42.6	2.1	45.2	40 24.7	3.1	45.8	41 06.3	4.1	46.4	41 47.5	5.0	47.0	42 28.1	6.1	47.7	43 08.3	7.1	48.4	53
54	38 17.4	-0.6	42.7	39 01.2	+0.4	43.3	39 44.7	1.3	43.9	40 27.8	2.2	44.4	41 10.4	3.1	45.0	41 52.5	4.2	45.7	42 34.2	5.2	46.3	43 15.4	6.2	47.0	54
55	38 16.8	-1.4	41.5	39 01.6	-0.6	42.0	39 46.0	+0.3	42.6	40 30.0	+1.3	43.1	41 13.5	+2.3	43.7	41 56.7	+3.2	44.3	42 39.4	-4.1	45.0	43 21.6	+5.1	45.6	55
56	38 15.4	2.2	40.2	39 01.0	1.3	40.7	39 46.3	-0.5	41.3	40 31.3	+0.4	41.8	41 15.8	1.3	42.4	41 59.9	2.2	43.0	42 43.5	3.2	43.6	43 26.7	4.2	44.3	56
57	38 13.2	3.1	38.9	38 59.7	2.3	39.4	39 45.8	1.3	40.0	40 31.7	-0.5	40.5	41 17.1	+0.4	41.1	42 02.1	1.3	41.7	42 46.7	2.3	42.3	43 30.9	3.2	42.9	57
58	38 10.1	3.9	37.7	38 57.4	3.0	38.1	39 44.5	2.3	38.7	40 31.2	1.4	39.2	41 17.5	-0.5	39.7	42 03.4	+0.4	40.3	42 49.0	1.3	40.9	43 34.1	2.2	41.5	58
59	38 06.2	4.7	36.4	38 54.4	3.9	36.9	39 42.2	3.1	37.4	40 29.8	2.3	37.9	41 17.0	1.5	38.4	42 03.8	-0.6	39.0	42 50.3	+0.3	39.5	43 36.3	1.3	40.1	59
60	38 01.5	-5.5	35.1	38 50.5	-4.8	35.6	39 39.1	-3.9	36.1	40 27.5	-3.2	36.6	41 15.5	-2.3	37.1	42 03.2	-1.5	37.6	42 50.6	-0.7	38.2	43 37.6	+0.2	38.8	60
61	37 56.0	6.3	33.9	38 45.7	5.6	34.3	39 35.2	4.9	34.8	40 24.3	4.1	35.2	41 13.2	3.3	35.7	42 01.7	2.5	36.3	42 49.9	1.6	36.8	43 37.8	-0.8	37.4	61
62	37 49.7	7.1	32.6	38 40.1	6.4	33.0	39 30.3	5.7	33.5	40 20.2	4.9	33.9	41 09.9	4.2	34.4	41 59.2	3.4	34.9	42 48.3	2.6	35.4	43 37.0	1.8	36.0	62
63	37 42.6	7.9	31.3	38 33.7	7.2	31.7	39 24.6	6.5	32.2	40 15.3	5.8	32.6	41 05.7	5.1	33.1	41 55.8	4.3	33.6	42 45.7	3.6	34.1	43 35.2	2.8	34.6	63
64	37 34.7	8.7	30.1	38 26.5	8.1	30.5	39 18.1	7.4	30.9	40 09.5	6.7	31.3	41 00.6	6.0	31.8	41 51.5	5.3	32.2	42 42.1	4.5	32.7	43 32.4	3.7	33.2	64
65	37 26.0	-9.5	28.8	38 18.4	-8.8	29.2	39 10.7	-8.2	29.6	40 02.8	-7.6	30.0	40 54.6	-6.9	30.5	41 46.2	-6.2	30.9	42 37.6	-5.5	31.4	43 28.7	-4.8	31.9	65
66	37 16.5	10.3	27.6	38 09.6	9.7	28.0	39 02.5	9.1	28.3	39 55.2	8.4	28.7	40 47.7	7.8	29.1	41 40.0	7.1	29.6	42 32.1	6.5	30.0	43 23.9	5.7	30.5	66
67	37 06.2	11.0	26.4	37 59.9	10.5	26.7	38 53.4	9.9	27.1	39 46.8	9.3	27.4	40 39.9	8.7	27.8	41 32.9	8.1	28.2	42 25.6	7.4	28.7	43 18.2	6.8	29.1	67
68	36 55.2	11.8	25.1	37 49.4	11.2	25.5	38 43.5	10.7	25.8	39 37.5	10.1	26.2	40 31.2	9.5	26.5	41 24.8	8.9	26.9	42 18.2	8.3	27.3	43 11.4	7.6	27.8	68
69	36 43.4	12.5	23.9	37 38.2	12.0	24.2	38 32.8	11.5	24.5	39 27.4	11.0	24.9	40 21.7	10.4	25.2	41 15.9	9.8	25.6	42 09.9	9.2	26.0	43 03.8	8.7	26.4	69
70	36 30.9	-13.3	22.7	37 26.2	-12.8	23.0	38 21.3	-12.3	23.3	39 16.4	-11.8	23.6	40 11.3	-11.3	23.9	41 06.1	-10.8	24.3	42 00.7	-10.2	24.7	42 55.1	-9.6	25.0	70
71	36 17.6	14.0	21.5	37 13.4	13.6	21.7	38 09.0	13.0	22.0	39 04.6	12.6	22.3	40 00.0	12.1	22.7	40 55.3	11.6	23.0	41 50.5	11.1	23.3	42 45.5	10.5	23.7	71
72	36 03.6	14.7	20.3	36 59.8	14.3	20.5	37 56.0	13.9	20.8	38 52.0	13.4	21.1	39 47.9	12.9	21.4	40 43.7	12.4	21.7	41 39.4	11.9	22.0	42 35.0	11.5	22.4	72
73	35 48.9	15.5	19.1	36 45.5	15.0	19.3	37 42.1	14.6	19.6	38 38.6	14.2	19.8	39 35.0	13.8	20.1	40 31.3	13.3	20.4	41 27.5	12.9	20.7	42 23.5	12.4	21.0	73
74	35 33.4	16.1	17.9	36 30.5	15.8	18.1	37 27.5	15.4	18.3	38 24.4	15.0	18.6	39 21.2	14.6	18.8	40 18.0	14.2	19.1	41 14.6	13.7	19.4	42 11.1	13.3	19.7	74
75	35 17.3	-16.8	16.7	36 14.7	-16.4	16.9	37 12.1	-16.1	17.1	38 09.4	-15.7	17.4	39 06.6	-15.3	17.6	40 03.8	15.0	17.8	41 00.9	14.6	18.1	41 57.8	-14.1	18.4	75
76	35 00.5	17.5	15.5	35 58.3	17.2	15.7	36 56.0	16.9	15.9	37 53.7	16.5	16.1	38 51.3	16.2	16.4	39 48.8	15.8	16.6	40 46.3	15.5	16.8	41 43.7	15.1	17.1	76
77	34 43.0	18.2	14.4	35 41.1	17.9	14.5	36 39.1	17.5	14.7	37 37.2	17.3	14.9	38 35.1	16.9	15.1	39 33.0	16.6	15.3	40 30.8	16.2	15.6	41 28.6	15.9	15.8	77
78	34 24.8	18.8	13.2	35 23.2	18.5	13.4	36 21.6	18.3	13.5	37 19.9	18.0	13.7	38 18.2	17.7	13.9	39 16.4	17.4	14.1	40 14.6	17.1	14.3	41 12.7	16.8	14.5	78
79	34 06.0	19.4	12.1	35 04.7	19.2	12.2	36 03.3	18.9	12.4	37 01.9	18.7	12.5	38 00.5	18.5	12.7	38 59.0	18.2	12.9	39 57.5	17.9	13.0	40 55.9	17.6	13.2	79
80	33 46.6	-20.1	10.9	34 45.5	-19.8	11.0	35 44.4	-19.6	11.2	36 43.2	-19.4	11.3	37 42.0	-19.1	11.5	38 40.8	-18.9	11.6	39 39.6	-18.7	11.8	40 38.3	-18.4	12.0	80
81	33 26.5	20.6	9.8	34 25.7	20.5	9.9	35 24.8	20.3	10.0	36 23.8	20.1	10.1	37 22.9	19.9	10.3	38 21.9	19.7	10.4	39 20.9	19.4	10.6	40 19.9	19.3	10.7	81
82	33 05.9	21.3	8.7	34 05.2	21.1	8.8	35 04.5	21.0	8.9	36 03.7	20.7	9.0	37 03.0	20.6	9.1	38 02.2	20.4	9.2	39 01.5	20.3	9.3	40 00.6	20.0	9.5	82
83	32 44.6	21.9	7.5	33 44.1	21.7	7.6	34 43.5	21.5	7.7	35 43.0	21.4	7.8	36 42.4	21.2	7.9	37 41.8	21.1	8.0	38 41.2	20.9	8.1	39 40.6	20.7	8.3	83
84	32 22.7	22.4	6.4	33 22.4	22.4	6.5	34 22.0	22.2	6.6	35 21.6	22.1	6.7	36 21.2	22.0	6.8	37 20.7	21.8	6.8	38 20.3	21.7	6.9	39 19.9	21.6	7.0	84
85	32 00.3	-23.0	5.3	33 00.0	-22.8	5.4	33 59.8	-22.8	5.5	34 59.5	-22.7	5.5	35 59.2	-22.6	5.6	36 58.9	-22.5	5.7	37 58.6	-22.3	5.8	38 58.3	-22.2	5.8	85
86	31 37.3	23.5	4.3	32 37.2	23.5	4.3	33 37.0	23.4	4.4	34 36.8	23.3	4.4	35 36.6	23.2	4.5	36 36.4	23.1	4.5	37 36.3	23.1	4.6	38 36.1	23.0	4.6	86
87	31 13.8	24.1	3.2	32 13.7	24.0	3.2	33 13.6	24.0	3.3	34 13.5	23.9	3.3	35 13.4	23.9	3.3	36 13.3	23.8	3.4	37 13.2	23.8	3.4	38 13.1	23.7	3.5	87
88	30 49.7	24.6	2.1	31 49.7	24.6	2.1	32 49.6	24.5	2.2	33 49.6	24.5	2.2	34 49.5	24.4	2.2	35 49.5	24.4	2.2	36 49.4	24.4	2.3	37 49.4	24.4	2.3	88
89	30 25.1	25.1	1.1	31 25.1	25.1	1.1	32 25.1	25.1	1.1	33 25.1	25.1	1.1	34 25.1	25.1	1.1	35 25.1	25.1	1.1	36 25.0	25.0	1.1	37 25.0	25.0	1.1	89
90	30 00.0	-25.6	0.0	31 00.0	-25.6	0.0	32 00.0	-25.6	0.0	33 00.0	-25.6	0.0	34 00.0	-25.6	0.0	35 00.0	-25.7	0.0	36 00.0	-25.7	0.0	37 00.0	-25.7	0.0	90
	30°			31°			32°			33°			34°			35°			36°			37°			

65°, 295° L.H.A. LATITUDE SAME NAME AS DECLINATION

Appendix J-2

INTERPOLATION TABLE

Dec. Inc.	Altitude Difference (d): Tens 10'	20'	30'	40'	50'	Decimals	Units 0'	1'	2'	3'	4'	5'	6'	7'	8'	9'
16.0	2.6	5.3	8.0	10.6	13.3	.0	0.0	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.5
16.1	2.7	5.3	8.0	10.7	13.4	.1	0.0	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.2	2.5
16.2	2.7	5.4	8.1	10.8	13.5	.2	0.1	0.3	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.5
16.3	2.7	5.4	8.1	10.9	13.6	.3	0.1	0.4	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6
16.4	2.7	5.5	8.2	10.9	13.7	.4	0.1	0.4	0.7	0.9	1.2	1.5	1.8	2.0	2.3	2.6
16.5	2.8	5.5	8.3	11.0	13.8	.5	0.1	0.4	0.7	1.0	1.2	1.5	1.8	2.1	2.3	2.6
16.6	2.8	5.5	8.3	11.1	13.8	.6	0.2	0.4	0.7	1.0	1.3	1.5	1.8	2.1	2.4	2.6
16.7	2.8	5.6	8.4	11.2	13.9	.7	0.2	0.5	0.7	1.0	1.3	1.6	1.8	2.1	2.4	2.7
16.8	2.8	5.6	8.4	11.2	14.0	.8	0.2	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4	2.7
16.9	2.9	5.7	8.5	11.3	14.1	.9	0.2	0.5	0.8	1.1	1.3	1.6	1.9	2.2	2.4	2.7
17.0	2.8	5.6	8.5	11.3	14.1	.0	0.0	0.3	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6
17.1	2.8	5.7	8.5	11.4	14.2	.1	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7
17.2	2.8	5.7	8.6	11.4	14.3	.2	0.1	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7
17.3	2.9	5.8	8.6	11.5	14.4	.3	0.1	0.4	0.7	1.0	1.3	1.5	1.8	2.1	2.4	2.7
17.4	2.9	5.8	8.7	11.6	14.5	.4	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.4	2.7
17.5	2.9	5.8	8.8	11.7	14.6	.5	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.5	2.8
17.6	2.9	5.9	8.8	11.7	14.7	.6	0.2	0.5	0.8	1.0	1.3	1.6	1.9	2.2	2.5	2.8
17.7	3.0	5.9	8.9	11.8	14.8	.7	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8
17.8	3.0	6.0	8.9	11.9	14.9	.8	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9
17.9	3.0	6.0	9.0	12.0	15.0	.9	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9
18.0	3.0	6.0	9.0	12.0	15.0	.0	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	2.8
18.1	3.0	6.0	9.0	12.0	15.1	.1	0.0	0.3	0.6	1.0	1.3	1.6	1.9	2.2	2.5	2.8
18.2	3.0	6.0	9.1	12.1	15.1	.2	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.5	2.8
18.3	3.0	6.1	9.1	12.2	15.2	.3	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.3	2.6	2.9
18.4	3.1	6.1	9.2	12.3	15.3	.4	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3	2.6	2.9
18.5	3.1	6.2	9.3	12.3	15.4	.5	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9
18.6	3.1	6.2	9.3	12.4	15.5	.6	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.3	2.7	3.0
18.7	3.1	6.3	9.4	12.5	15.6	.7	0.2	0.5	0.8	1.1	1.4	1.8	2.1	2.4	2.7	3.0
18.8	3.2	6.3	9.4	12.6	15.7	.8	0.2	0.5	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
18.9	3.2	6.3	9.5	12.6	15.8	.9	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.1
19.0	3.1	6.3	9.5	12.6	15.8	.0	0.0	0.3	0.6	1.0	1.3	1.6	1.9	2.3	2.6	2.9
19.1	3.2	6.3	9.5	12.7	15.9	.1	0.0	0.4	0.7	1.0	1.3	1.7	2.0	2.3	2.6	3.0
19.2	3.2	6.4	9.6	12.8	16.0	.2	0.1	0.4	0.7	1.0	1.4	1.7	2.0	2.3	2.7	3.0
19.3	3.2	6.4	9.6	12.9	16.1	.3	0.1	0.4	0.7	1.1	1.4	1.7	2.0	2.4	2.7	3.0
19.4	3.2	6.5	9.7	12.9	16.2	.4	0.1	0.5	0.8	1.1	1.4	1.8	2.1	2.4	2.7	3.1
19.5	3.3	6.5	9.8	13.0	16.3	.5	0.2	0.5	0.8	1.1	1.5	1.8	2.1	2.4	2.8	3.1
19.6	3.3	6.5	9.8	13.1	16.3	.6	0.2	0.5	0.8	1.2	1.5	1.8	2.1	2.5	2.8	3.1
19.7	3.3	6.6	9.9	13.2	16.4	.7	0.2	0.6	0.9	1.2	1.5	1.9	2.2	2.5	2.8	3.2
19.8	3.3	6.6	9.9	13.2	16.5	.8	0.3	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.9	3.2
19.9	3.4	6.7	10.0	13.3	16.6	.9	0.3	0.6	0.9	1.3	1.6	1.9	2.2	2.6	2.9	3.2
20.0	3.3	6.6	10.0	13.3	16.6	.0	0.0	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.1
20.1	3.3	6.7	10.0	13.4	16.7	.1	0.0	0.4	0.7	1.1	1.4	1.7	2.1	2.4	2.8	3.1
20.2	3.3	6.7	10.1	13.4	16.8	.2	0.1	0.4	0.8	1.1	1.4	1.8	2.1	2.5	2.8	3.1
20.3	3.4	6.8	10.1	13.5	16.9	.3	0.1	0.4	0.8	1.1	1.5	1.8	2.2	2.5	2.8	3.2
20.4	3.4	6.8	10.2	13.6	17.0	.4	0.1	0.5	0.8	1.2	1.5	1.8	2.2	2.5	2.9	3.2
20.5	3.4	6.8	10.3	13.7	17.1	.5	0.2	0.5	0.9	1.2	1.5	1.9	2.2	2.6	2.9	3.2
20.6	3.4	6.9	10.3	13.7	17.2	.6	0.2	0.5	0.9	1.2	1.6	1.9	2.3	2.6	2.9	3.3
20.7	3.5	6.9	10.4	13.8	17.3	.7	0.2	0.6	0.9	1.3	1.6	1.9	2.3	2.6	3.0	3.3
20.8	3.5	7.0	10.4	13.9	17.4	.8	0.3	0.6	1.0	1.3	1.6	2.0	2.3	2.7	3.0	3.3
20.9	3.5	7.0	10.5	14.0	17.5	.9	0.3	0.6	1.0	1.3	1.7	2.0	2.4	2.7	3.0	3.4
21.0	3.5	7.0	10.5	14.0	17.5	.0	0.0	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.9	3.2
21.1	3.5	7.0	10.5	14.0	17.6	.1	0.0	0.4	0.8	1.1	1.5	1.8	2.2	2.5	2.9	3.3
21.2	3.5	7.0	10.6	14.1	17.6	.2	0.1	0.4	0.8	1.1	1.5	1.9	2.2	2.6	2.9	3.3
21.3	3.5	7.1	10.6	14.2	17.7	.3	0.1	0.5	0.8	1.2	1.5	1.9	2.3	2.6	3.0	3.3
21.4	3.6	7.1	10.7	14.3	17.8	.4	0.1	0.5	0.9	1.2	1.6	1.9	2.3	2.7	3.0	3.4
21.5	3.6	7.2	10.8	14.3	17.9	.5	0.2	0.5	0.9	1.3	1.6	2.0	2.3	2.7	3.0	3.4
21.6	3.6	7.2	10.8	14.4	18.0	.6	0.2	0.6	0.9	1.3	1.6	2.0	2.4	2.7	3.1	3.4
21.7	3.6	7.3	10.9	14.5	18.1	.7	0.3	0.6	1.0	1.3	1.7	2.0	2.4	2.8	3.1	3.5
21.8	3.7	7.3	10.9	14.6	18.2	.8	0.3	0.6	1.0	1.4	1.7	2.1	2.4	2.8	3.2	3.5
21.9	3.7	7.3	11.0	14.6	18.3	.9	0.3	0.7	1.0	1.4	1.8	2.1	2.5	2.8	3.2	3.5
22.0	3.6	7.3	11.0	14.6	18.3	.0	0.0	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.4
22.1	3.7	7.3	11.0	14.7	18.4	.1	0.0	0.4	0.8	1.2	1.5	1.9	2.3	2.7	3.0	3.4
22.2	3.7	7.4	11.1	14.8	18.5	.2	0.1	0.4	0.8	1.2	1.6	1.9	2.3	2.7	3.1	3.4
22.3	3.7	7.4	11.1	14.9	18.6	.3	0.1	0.5	0.9	1.2	1.6	2.0	2.4	2.7	3.1	3.5
22.4	3.7	7.5	11.2	14.9	18.7	.4	0.1	0.5	0.9	1.3	1.6	2.0	2.4	2.8	3.1	3.5
22.5	3.8	7.5	11.3	15.0	18.8	.5	0.2	0.6	0.9	1.3	1.7	2.1	2.4	2.8	3.2	3.6
22.6	3.8	7.5	11.3	15.1	18.8	.6	0.2	0.6	1.0	1.3	1.7	2.1	2.5	2.8	3.2	3.6
22.7	3.8	7.6	11.4	15.2	18.9	.7	0.3	0.6	1.0	1.4	1.8	2.1	2.5	2.9	3.3	3.6
22.8	3.8	7.6	11.4	15.2	19.0	.8	0.3	0.7	1.0	1.4	1.8	2.2	2.5	2.9	3.3	3.7
22.9	3.9	7.7	11.5	15.3	19.1	.9	0.3	0.7	1.1	1.5	1.8	2.2	2.6	3.0	3.3	3.7
23.0	3.8	7.6	11.5	15.3	19.1	.0	0.0	0.4	0.8	1.2	1.6	2.0	2.3	2.7	3.1	3.5
23.1	3.8	7.7	11.5	15.4	19.2	.1	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6
23.2	3.8	7.7	11.6	15.4	19.3	.2	0.1	0.5	0.9	1.3	1.6	2.0	2.4	2.8	3.2	3.6
23.3	3.9	7.8	11.6	15.5	19.4	.3	0.1	0.5	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.6
23.4	3.9	7.8	11.7	15.6	19.5	.4	0.2	0.5	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.7
23.5	3.9	7.8	11.8	15.7	19.6	.5	0.2	0.6	1.0	1.4	1.8	2.2	2.5	2.9	3.3	3.7
23.6	3.9	7.9	11.8	15.7	19.7	.6	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8
23.7	4.0	7.9	11.9	15.8	19.8	.7	0.3	0.7	1.1	1.4	1.8	2.2	2.6	3.0	3.4	3.8
23.8	4.0	8.0	11.9	15.9	19.9	.8	0.3	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.4	3.8
23.9	4.0	[illegible]	[illegible]	16.0	20.0	.9	0.4	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.5	3.9
	10'	20'	30'	40'	50'		0'	1'	2'	3'	4'	5'	6'	7'	8'	9'

Double Second Diff. and Corr. (Dec. Inc. 16.0–17.9)

Double Second Diff.	Corr.
1.0	
	0.1
3.0	
	0.2
4.9	
	0.3
6.9	
	0.4
8.9	
	0.5
10.8	
	0.6
12.8	
	0.7
14.8	
	0.8
16.7	
	0.9
18.7	
	1.0
20.7	
	1.1
22.7	
	1.2
24.6	
	1.3
26.6	
	1.4
28.6	
	1.5
30.5	
	1.6
32.5	
	1.7
34.5	

Double Second Diff. and Corr. (Dec. Inc. 18.0–19.9)

Double Second Diff.	Corr.
0.9	
	0.1
2.8	
	0.2
4.6	
	0.3
6.5	
	0.4
8.3	
	0.5
10.2	
	0.6
12.0	
	0.7
13.9	
	0.8
15.7	
	0.9
17.6	
	1.0
19.4	
	1.1
21.3	
	1.2
23.1	
	1.3
25.0	
	1.4
26.8	
	1.5
28.7	
	1.6
30.5	
	1.7
32.3	
	1.8
34.2	

Double Second Diff. and Corr. (Dec. Inc. 20.0–21.9)

Double Second Diff.	Corr.
0.9	
	0.1
2.6	
	0.2
4.4	
	0.3
6.2	
	0.4
7.9	
	0.5
9.7	
	0.6
11.4	
	0.7
13.2	
	0.8
14.9	
	0.9
16.7	
	1.0
18.5	
	1.1
20.2	
	1.2
22.0	
	1.3
23.7	
	1.4
25.5	
	1.5
27.3	
	1.6
29.0	
	1.7
30.8	
	1.8
32.5	
	1.9
34.3	

Double Second Diff. and Corr. (Dec. Inc. 22.0–23.9)

Double Second Diff.	Corr.
0.8	
	0.1
2.5	
	0.2
4.2	
	0.3
5.9	
	0.4
7.6	
	0.5
9.3	
	0.6
11.0	
	0.7
12.7	
	0.8
14.4	
	0.9
16.1	
	1.0
17.8	
	1.1
19.5	
	1.2
21.2	
	1.3
22.8	
	1.4
24.5	
	1.5
26.2	
	1.6
27.9	
	1.7
29.6	
	1.8
31.3	
	1.9
33.0	
	2.0
34.7	

Dec. Inc.	Altitude Difference (d): Tens 10'	20'	30'	40'	50'	Decimals	Units 0'	1'	2'	3'	4'	5'	6'	7'	8'	9'
24.0	4.0	8.0	12.0	16.0	20.0	.0	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.9	3.3	3.7
24.1	4.0	8.0	12.0	16.0	20.1	.1	0.0	0.4	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.7
24.2	4.0	8.0	12.1	16.1	20.1	.2	0.1	0.5	0.9	1.3	1.7	2.1	2.5	2.9	3.3	3.8
24.3	4.0	8.1	12.1	16.2	20.2	.3	0.1	0.5	0.9	1.3	1.8	2.2	2.6	3.0	3.4	3.8
24.4	4.1	8.1	12.2	16.3	20.3	.4	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8
24.5	4.1	8.2	12.3	16.3	20.4	.5	0.2	0.6	1.0	1.4	1.8	2.2	2.7	3.1	3.5	3.9
24.6	4.1	8.2	12.3	16.4	20.5	.6	0.2	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.5	3.9
24.7	4.1	8.3	12.4	16.5	20.6	.7	0.3	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.6	4.0
24.8	4.2	8.3	12.4	16.6	20.7	.8	0.3	0.7	1.1	1.6	2.0	2.4	2.8	3.2	3.6	4.0
24.9	4.2	8.3	12.5	16.6	20.8	.9	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
25.0	4.1	8.3	12.5	16.6	20.8	.0	0.0	0.4	0.8	1.3	1.7	2.1	2.5	3.0	3.4	3.8
25.1	4.2	8.3	12.5	16.7	20.9	.1	0.0	0.5	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.9
25.2	4.2	8.4	12.6	16.8	21.0	.2	0.1	0.5	0.9	1.4	1.8	2.2	2.6	3.1	3.5	3.9
25.3	4.2	8.4	12.6	16.9	21.1	.3	0.1	0.6	1.0	1.4	1.8	2.3	2.7	3.1	3.5	4.0
25.4	4.2	8.5	12.7	16.9	21.2	.4	0.2	0.6	1.0	1.4	1.9	2.3	2.7	3.1	3.6	4.0
25.5	4.3	8.5	12.8	17.0	21.3	.5	0.2	0.6	1.1	1.5	1.9	2.3	2.8	3.2	3.6	4.0
25.6	4.3	8.5	12.8	17.1	21.3	.6	0.3	0.7	1.1	1.5	2.0	2.4	2.8	3.2	3.7	4.1
25.7	4.3	8.6	12.9	17.2	21.4	.7	0.3	0.7	1.1	1.6	2.0	2.4	2.8	3.3	3.7	4.1
25.8	4.3	8.6	12.9	17.2	21.5	.8	0.3	0.8	1.2	1.6	2.0	2.5	2.9	3.3	3.7	4.2
25.9	4.4	8.7	13.0	17.3	21.6	.9	0.4	0.8	1.2	1.7	2.1	2.5	2.9	3.4	3.8	4.2
26.0	4.3	8.6	13.0	17.3	21.6	.0	0.0	0.4	0.9	1.3	1.8	2.2	2.6	3.1	3.5	4.0
26.1	4.3	8.7	13.0	17.4	21.7	.1	0.0	0.5	0.9	1.4	1.8	2.3	2.7	3.1	3.6	4.0
26.2	4.3	8.7	13.1	17.4	21.8	.2	0.1	0.5	1.0	1.4	1.9	2.3	2.7	3.2	3.6	4.1
26.3	4.4	8.8	13.1	17.5	21.9	.3	0.1	0.6	1.0	1.5	1.9	2.3	2.8	3.2	3.7	4.1
26.4	4.4	8.8	13.2	17.6	22.0	.4	0.2	0.6	1.1	1.5	1.9	2.4	2.8	3.3	3.7	4.2
26.5	4.4	8.8	13.3	17.7	22.1	.5	0.2	0.7	1.1	1.5	2.0	2.4	2.9	3.3	3.8	4.2
26.6	4.4	8.9	13.3	17.7	22.2	.6	0.3	0.7	1.1	1.6	2.0	2.5	2.9	3.4	3.8	4.2
26.7	4.5	8.9	13.4	17.8	22.3	.7	0.3	0.8	1.2	1.6	2.1	2.5	3.0	3.4	3.8	4.3
26.8	4.5	9.0	13.4	17.9	22.4	.8	0.4	0.8	1.2	1.7	2.1	2.6	3.0	3.4	3.9	4.3
26.9	4.5	9.0	13.5	18.0	22.5	.9	[illegible]	0.8	1.3	1.7	2.2	2.6	3.0	3.5	3.9	4.4
27.0	4.5	9.0	13.5	18.0	22.5	.0	0.0	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.7	4.1
27.1	4.5	9.0	13.5	18.0	22.6	.1	0.0	0.5	1.0	1.4	1.9	2.3	2.8	3.3	3.7	4.2
27.2	4.5	9.0	13.6	18.1	22.6	.2	0.1	0.5	1.0	1.5	1.9	2.4	2.8	3.3	3.8	4.2
27.3	4.5	9.1	13.6	18.2	22.7	.3	0.1	0.6	1.1	1.5	2.0	2.4	2.9	3.3	3.8	4.3
27.4	4.6	9.1	13.7	18.3	22.8	.4	0.2	0.6	1.1	1.6	2.0	2.5	2.9	3.4	3.8	4.3
27.5	4.6	9.2	13.8	18.3	22.9	.5	0.2	0.7	1.1	1.6	2.1	2.5	3.0	3.4	3.9	4.4
27.6	4.6	9.2	13.8	18.4	23.0	.6	0.3	0.7	1.2	1.6	2.1	2.6	3.0	3.5	3.9	4.4
27.7	4.6	9.3	13.9	18.5	23.1	.7	0.3	0.8	1.2	1.7	2.2	2.6	3.1	3.5	4.0	4.4
27.8	4.7	9.3	13.9	18.6	23.2	.8	0.4	0.8	1.3	1.7	2.2	2.7	3.1	3.6	4.0	4.5
27.9	4.7	9.3	14.0	18.6	23.3	.9	0.4	0.9	1.3	1.8	2.2	2.7	3.2	3.6	4.1	4.5
28.0	4.6	9.3	14.0	18.6	23.3	.0	0.0	0.5	0.9	1.4	1.9	2.4	2.8	3.3	3.8	4.3
28.1	4.7	9.3	14.0	18.7	23.4	.1	0.0	0.5	1.0	1.5	1.9	2.4	2.9	3.4	3.8	4.3
28.2	4.7	9.4	14.1	18.8	23.5	.2	0.1	0.6	1.0	1.5	2.0	2.5	2.9	3.4	3.9	4.4
28.3	4.7	9.4	14.1	18.9	23.6	.3	0.1	0.6	1.1	1.6	2.0	2.5	3.0	3.5	3.9	4.4
28.4	4.7	9.5	14.2	18.9	23.7	.4	0.2	0.7	1.1	1.6	2.1	2.6	3.0	3.5	4.0	4.5
28.5	4.8	9.5	14.3	19.0	23.8	.5	0.2	0.7	1.2	1.7	2.1	2.6	3.1	3.6	4.0	4.5
28.6	4.8	9.5	14.3	19.1	23.8	.6	0.3	0.8	1.2	1.7	2.2	2.7	3.1	3.6	4.1	4.6
28.7	4.8	9.6	14.4	19.2	23.9	.7	0.3	0.8	1.3	1.8	2.2	2.7	3.2	3.7	4.1	4.6
28.8	4.8	9.6	14.4	19.2	24.0	.8	0.4	0.9	1.3	1.8	2.3	2.8	3.2	3.7	4.2	4.7
28.9	4.9	9.7	14.5	19.3	24.1	.9	0.4	0.9	1.4	1.9	2.3	2.8	3.3	3.8	4.2	4.7
29.0	4.8	9.6	14.5	19.3	24.1	.0	0.0	0.5	1.0	1.5	2.0	2.5	2.9	3.4	3.9	4.4
29.1	4.8	9.7	14.5	19.4	24.2	.1	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
29.2	4.8	9.7	14.6	19.4	24.3	.2	0.1	0.6	1.1	1.6	2.1	2.6	3.0	3.5	4.0	4.5
29.3	4.9	9.8	14.6	19.5	24.4	.3	0.1	0.6	1.1	1.6	2.1	2.6	3.1	3.6	4.1	4.6
29.4	4.9	9.8	14.7	19.6	24.5	.4	0.2	0.7	1.2	1.7	2.2	2.7	3.1	3.6	4.1	4.6
29.5	4.9	9.8	14.8	19.7	24.6	.5	0.2	0.7	1.2	1.7	2.2	2.7	3.2	3.7	4.2	4.7
29.6	4.9	9.9	14.8	19.7	24.7	.6	0.3	0.8	1.3	1.8	2.3	2.8	3.2	3.7	4.2	4.7
29.7	5.0	9.9	14.9	19.8	24.8	.7	0.3	0.8	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8
29.8	5.0	10.0	14.9	19.9	24.9	.8	0.4	0.9	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8
29.9	5.0	10.0	15.0	20.0	25.0	.9	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.4	4.9
30.0	5.0	10.0	15.0	20.0	25.0	.0	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.6	4.1	4.6
30.1	5.0	10.0	15.0	20.0	25.1	.1	0.1	0.6	1.1	1.6	2.1	2.6	3.1	3.6	4.1	4.6
30.2	5.0	10.0	15.1	20.1	25.1	.2	0.1	0.6	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7
30.3	5.0	10.1	15.1	20.2	25.2	.3	0.2	0.7	1.2	1.7	2.2	2.7	3.2	3.7	4.2	4.7
30.4	5.1	10.1	15.2	20.3	25.3	.4	0.2	0.7	1.2	1.7	2.2	2.7	3.3	3.8	4.3	4.8
30.5	5.1	10.2	15.3	20.3	25.4	.5	0.3	0.8	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8
30.6	5.1	10.2	15.3	20.4	25.5	.6	0.3	0.8	1.3	1.8	2.3	2.8	3.4	3.9	4.4	4.9
30.7	5.1	10.3	15.4	20.5	25.6	.7	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.4	4.9
30.8	5.2	10.3	15.4	20.6	25.7	.8	0.4	0.9	1.4	1.9	2.4	2.9	3.5	4.0	4.5	5.0
30.9	5.2	10.3	15.5	20.6	25.8	.9	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
31.0	5.1	10.3	15.5	20.6	25.8	.0	0.0	0.5	1.0	1.6	2.1	2.6	3.1	3.7	4.2	4.7
31.1	5.2	10.3	15.5	20.7	25.9	.1	0.1	0.6	1.1	1.6	2.2	2.7	3.2	3.7	4.3	4.8
31.2	5.2	10.4	15.6	20.8	26.0	.2	0.1	0.6	1.2	1.7	2.2	2.7	3.2	3.8	4.3	4.8
31.3	5.2	10.4	15.6	20.9	26.1	.3	0.2	0.7	1.2	1.7	2.3	2.8	3.3	3.8	4.4	4.9
31.4	5.2	10.5	15.7	20.9	26.2	.4	0.2	0.7	1.3	1.8	2.3	2.8	3.4	3.9	4.4	4.9
31.5	5.3	10.5	15.8	21.0	26.3	.5	0.3	0.8	1.3	1.8	2.4	2.9	3.4	3.9	4.5	5.0
31.6	5.3	10.5	15.8	21.1	26.3	.6	0.3	0.8	1.4	1.9	2.4	2.9	3.5	4.0	4.5	5.0
31.7	5.3	10.6	15.9	21.2	26.4	.7	0.4	0.9	1.4	1.9	2.5	3.0	3.5	4.0	4.6	5.1
31.8	5.3	10.6	15.9	21.2	26.5	.8	0.4	0.9	1.5	2.0	2.5	3.0	3.6	4.1	4.6	5.1
31.9	5.4	10.7	16.0	21.3	26.6	.9	0.5	1.0	1.5	2.0	2.6	3.1	3.6	4.1	4.7	5.2
	10'	20'	30'	40'	50'		0'	1'	2'	3'	4'	5'	6'	7'	8'	9'

Double Second Diff. and Corr. (Dec. Inc. 24.0–25.9)

Double Second Diff.	Corr.
0.8	
	0.1
2.5	
	0.2
4.1	
	0.3
5.8	
	0.4
7.4	
	0.5
9.1	
	0.6
10.7	
	0.7
12.3	
	0.8
14.0	
	0.9
15.6	
	1.0
17.3	
	1.1
18.9	
	1.2
20.6	
	1.3
22.2	
	1.4
23.9	
	1.5
25.5	
	1.6
27.2	
	1.7
28.8	
	1.8
30.4	
	1.9
32.1	
	2.0
33.7	
	2.1
35.4	

Double Second Diff. and Corr. (Dec. Inc. 26.0–27.9)

Double Second Diff.	Corr.
0.8	
	0.1
2.4	
	0.2
4.0	
	0.3
5.7	
	0.4
7.3	
	0.5
8.9	
	0.6
10.5	
	0.7
12.1	
	0.8
13.7	
	0.9
15.4	
	1.0
17.0	
	1.1
18.6	
	1.2
20.2	
	1.3
21.8	
	1.4
23.4	
	1.5
25.1	
	1.6
26.7	
	1.7
28.3	
	1.8
29.9	
	1.9
31.5	
	2.0
33.1	
	2.1
34.7	

Double Second Diff. and Corr. (Dec. Inc. 28.0–29.9)

Double Second Diff.	Corr.
0.8	
	0.1
2.4	
	0.2
4.0	
	0.3
5.6	
	0.4
7.2	
	0.5
8.8	
	0.6
10.4	
	0.7
12.0	
	0.8
13.6	
	0.9
15.2	
	1.0
16.8	
	1.1
18.4	
	1.2
20.0	
	1.3
21.6	
	1.4
23.2	
	1.5
24.8	
	1.6
26.4	
	1.7
28.0	
	1.8
29.6	
	1.9
31.2	
	2.0
32.8	
	2.1
34.4	

Double Second Diff. and Corr. (Dec. Inc. 30.0–31.9)

Double Second Diff.	Corr.
0.8	
	0.1
2.4	
	0.2
4.0	
	0.3
5.6	
	0.4
7.2	
	0.5
8.8	
	0.6
10.4	
	0.7
12.0	
	0.8
13.6	
	0.9
15.2	
	1.0
16.8	
	1.1
18.4	
	1.2
20.0	
	1.3
21.6	
	1.4
23.2	
	1.5
24.8	
	1.6
26.4	
	1.7
28.0	
	1.8
29.6	
	1.9
31.2	
	2.0
32.8	
	2.1
34.4	

The Double Second Difference correction (Corr.) is always to be added to the tabulated altitude.

Appendix K-1

U.S.
NAVY
NAVIGATION
WORKBOOK

U.S.S.________________________

PERIOD

________________19__ TO _______________19__

OPNAV FORM 3530/1 and 1A thru 1J (Rev. 7-71)

ENCLOSURE (1)

Appendix K-2

NAVIGATION WORKBOOK

U.S. Navy Regulations require the navigator to "Maintain record books of all observations and computations made for the purpose of navigating the ship, with results and dates involved. Such books shall form a part of the ship's official records." This publication has been printed to meet a recognized need for a standard computation book. In addition to providing a standard record, the format is intended to provide optimum utility, economy and flexibility, by providing strip inserts to assist the navigator in the below computations: (Strip inserts, marked to size for cut out, are printed on the back pages of this book. An envelope, suitable for stowing inserts when not in use, is attached to the inside back cover.)

CELESTIAL SIGHTS and LORAN

Place proper Computation Strip beside a blank column, and align so that entries will correspond with information on strip. Insure name of celestial body or "LORAN" is entered at top, and that the Fix is entered for appropriate celestial sights or LORAN LOPs.

AZIMUTH, LAN, SUNRISE/SUNSET, TIDES, CURRENTS, etc.

Place proper Computation Strip beside a blank column. Insure top of column is labeled to identify the type of computation.

MODIFICATION OF COMPUTATION STRIPS

This workbook is to serve navigators, and strip forms may be used to suit individual preference. Note: Any modified strip form is to become an official part of this record.

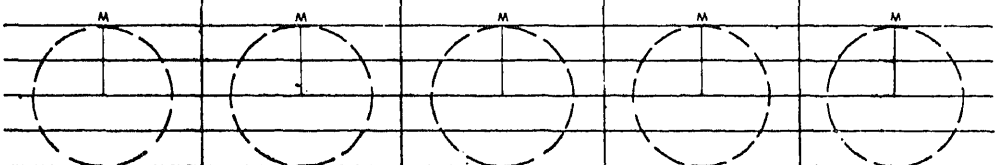
NAVIGATOR'S SIGNATURE

Space is provided at the bottom of each page for required signature of the navigator.

Appendix K-3

NAVIGATION WORKBOOK
OPNAV FORM 3530/1 (Rev. 7-71)

DATE DR POSIT	DATE DR POSIT	DATE DR POSIT	DATE DR POSIT	DATE DR POSIT



				USN, NAVIGATOR

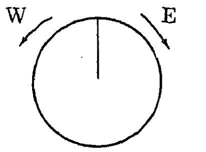
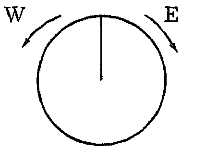
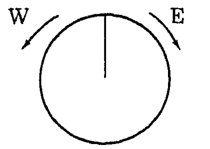
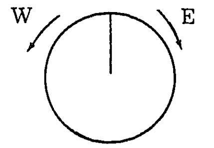
Appendix K-4

OPNAV FORM 3530/1A (7-71)	OPNAV FORM 3530/1B (7-71)	OPNAV FORM 3530/1C (7-71)	OPNAV FORM 3530/1D (7-71)	OPNAV FORM 3530/1E (7-71)	OPNAV FORM 3530/1F (7-71)	OPNAV FORM 3530/1G (7-71)
H.O. 214	H.O. 249 VOL I	H.O. 229	LATITUDE BY POLARIS	LAN (TIME)	AZIMUTH BY H.O. 214	AZIMUTH BY H.O. 229
Body	Body	Body	Body (Polaris)	Sun (UL, LL)	Body	Body
GMT	GMT	GMT	GMT	DRλ	GMT	GMT
IC (±)	IC (±)	IC (±)	IC (±)	LMT	DR Lat	DR Lat
Dip (−)	Dip (−)	Dip (−)	Dip (−)	λ arc to time	GHA*	GHA*
hs	hs	hs	hs	GMT	Increment (+)	Increment (+)
Sum	Sum	Sum	Sum	ZD (rev.)	Total GHA	GHA
ha	ha	ha	ha	ZT (first est.)	DRλ (+E, −W)	DRλ (+E, −W)
R	R	R	R	DRλ (at first est.)	LHA	LHA
Corr'n	Corr'n	Corr'n	Corr'n	LMT	t (E or W)	Tab Dec
Ho	Ho	Ho	Ho	λ arc to time	Tab Dec	d corr'n (±)
GHA*	GHA♈*	GHA*		GMT	d corr'n (±)	True Dec
Increment (+)	Increment (+)	Increment (+)	GHA♈*	ZD (rev)	True Dec	LHA Inc × Z diff
SHA or v corr'n	Total GHA♈	SHA or v corr'n	Increment (+)	ZT (2nd est.)		Dec Inc XZ diff
Total GHA	aλ (+E, −W)	Total GHA	Total GHA♈		t corr'n	Lat Inc XZ diff
aλ (+E, −W)	LHA♈	aλ (+E, −W)	DRλ (+E, −W)	LAN (Lat.)	Dec corr'n	Total Corr'n
LHA		LHA	LHA♈	IC (±)	Lat corr'n	Tab Z
t (E or W)	aLat	Tab Dec		Dip (−)	Tab Az	Exact Z
Tab Dec	Hc	d corr'n (±)	Ho	hs	Exact Az	Exact Zn
d corr'n (±)	Ho	True Dec	a0 (+)	Sum	Zn	Gyro Brg
True Dec	a (T or A)	d Dec	a1 (+)	ha	Gyro Brg	G.E. (E or W)
d Dec	Zn	Dec Inc	a2 (+)	R	G.E. (E or W)	
Dec Diff		d (±)	Sum	Ho		time
Δd (±)	Fix L	Hc (Tab)	−1°00'	Tab Dec	time	
Dec Diff × Δd (±)	λ	Dec Inc × d (±)	Latitude	d corr'n (±)		
ht	Precession Corr'n	DSD		True Dec		
Hc	time	Hc				
Ho		Ho		90 Ho		
a (T or A)		a (T or A)		True Dec		
L (Az) t		Z		Lat		
Zn		Zn				
Fix L		Fix L		time		
λ		λ				
time		time				

Appendix K-5

OPNAV FORM 3530/1H (7-71)	OPNAV FORM 3530/1I (7-71)	OPNAV FORM 3530/1J (7-71)	
LORAN	SUNRISE/SET TWILIGHT	MOONRISE/SET	
Rate	Date	Date	
DR Lat	DR Lat	DR Lat	
DRλ	TABLE I:	TABLE I:	
TG/TS	Tab Interval	Tab Interval	
Sys Corr'n	Lat diff	Lat Diff	
Skywave corr'n	Time diff	Time Diff	
TG	Time Corr'n	Time Corr'n	
Lat/Lon for T	Tab LMT	Tab LMT	
T from Table	LMT	LMT	
TG	DRλ	DRλ	
TG − T (±)	λ arc to time	TABLE II:	
(TG − T)(Δ)(±)	LMT	Tab LMT today	
Tab Lat/Lon	GMT	LMT (preceding/following)	
Adj Lat/Lon	ZD (rev.)	time Difference	
	ZT (1st est.)	time corr'n	
	DRλ (1st est.)	LMT	
Fix Lat	LMT	LMT actual	
	λ arc to time	λ arc to time	
time	GMT	GMT	
	ZD (rev)	ZD (rev)	
	ZT (2nd est.)	ZT (1st est)	
		DRλ (1st est)	
		λ arc to time	
		LMT Actual	
		GMT	
		ZD (rev)	
		ZT (2nd est)	

Appendix L-1

LOCAL DATE: ________ COURSE ______ °T SPEED ______								
DR: LAT. LONG.								
BODY								
Z.T. Z.D.								
GMT Gr. Date								
GHA (hrs) GHA (m & s) v corr. or SHA*								
GHA a Long.	E/W		E/W		E/W		E/W	
LHA t (H.A.)								
Dec. Tab. d. corr. (±)	( )		( )		( )		( )	
Dec.	N/S		N/S		N/S		N/S	
ENTER H.O. 214 — Dec. t (H.A.) a Lat.		N/S E/W N/S		N/S E/W N/S		N/S E/W N/S		N/S E/W N/S
d. diff. d (+ or -)								
Ht corr.								
Hc Az	N/S	E/W	N/S	E/W	N/S	E/W	N/S	E/W
	+	-	+	-	+	-	+	-
I.C. Dip Main Corr. Add'l								
SUMS								
Hs Corr.								
Ho Hc								
a Zn		T/A °T		T/A °T		T/A °T		T/A °T
Advance								

An alternate form for multiple sight computations

Appendix L-2

PREDICTING TIME OF SUNS MERIDIAN PASSAGE (LAN)

S. M.

← + W | - E →

* DLo BTN STANDARD MERIDIAN & DR LONGITUDE

1200 DR LAT	
DR LONG	
LOCAL DATE	
LMT OF MER PASS	
* DLo (IN TIME)	
PREDICTED ZT OF MER PASS	

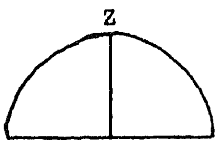
SOLUTION FOR LATITUDE	
ACT ZT OF MER PASS	
ZD (+W) (-E)	
GMT	
GR DATE	
TAB DEC	
d CORR ( ) ±	
TOTAL DEC	

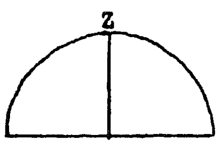
	+	-
I. C.		
DIP		
MAIN CORR		
SUMS (+)		
SUMS (-)		
TOTAL CORR		
HS		
HO		
ZENITH	8 9°-6 0. 0'	
ZEN DIST		
TOTAL DEC		
LATITUDE		

L & D SAME L +
(L = D + ZD)

L & D SAME D +
(L = D - ZD)

L & D CONTRARY
(L = ZD - D)





S. M.

← + W | - E →

DLo BTN STANDARD MERIDIAN & DR LONGITUDE

1200 DR LAT	
DR LONG	
LOCAL DATE	
LMT OF MER PASS	
DLo (IN TIME)	
PREDICTED ZT OF MER PASS	

SOLUTION FOR LATITUDE	
ACT ZT OF MER PASS	
ZD (+W) (-E)	
GMT	
GR DATE	
TAB DEC	
d CORR ( ) ±	
TOTAL DEC	

	+	-
I. C.		
DIP		
MAIN CORR		
SUMS (+)		
SUMS (-)		
TOTAL CORR		
HS		
HO		
ZENITH	8 9°- 6 0. 0'	
ZEN DIST		
TOTAL DEC		
LATITUDE		

Appendix L-3

LATITUDE BY POLARIS

LATITUDE = CORRECTED SEXTANT ALTITUDE - $1^{\circ} + a_0 + a_1 + a_2$

DATE (LOCAL)		DATE (LOCAL)	
DR LATITUDE		DR LATITUDE	
DR LONGITUDE		DR LONGITUDE	
ZT		ZT	
ZD (+W) (-E)		ZD (+W) (-E)	
GMT		GMT	
GR DATE		GR DATE	
GHA ARIES (hrs)		GHA ARIES (hrs)	
GHA ARIES (m&s)		GHA ARIES (m&s)	
TOTAL GHA ARIES		TOTAL GHA ARIES	
DR LONG (+E) (-W)		DR LONG (+E) (-W)	
LHA ARIES		LHA ARIES	

	+	-		+	-
IC			IC		
DIP			DIP		
MAIN CORR			MAIN CORR		
a_0 (LHA)			a_0 (LHA)		
a_1 (LAT)			a_1 (LAT)		
a_2 (MONTH)			a_2 (MONTH)		
ADD'L		60.0'	ADD'L		60.0'
SUMS (+)			SUMS (+)		
SUMS (-)			SUMS (-)		
TOTAL CORR			TOTAL CORR		
Hs			Hs		
LATITUDE		N	LATITUDE		N

Appendix L-4

SUNRISE, SUNSET & LHA ARIES

S. M.

+ W ← | → - E

** Dlo BTN STANDARD MERIDIAN & DR LONGITUDE

DATE ________ SUN	
DR LATITUDE ________	
DR LONGITUDE ________	
STANDARD MERIDIAN	
** DIFF IN LONGITUDE	
SUN ____ LAT ________ ( )	
SUN ____ LAT ________ ( )	
1° LAT = ________	
DIFF IN LAT = ____ X ____	
DIFF IN LONG = ____ X 4m =	
TOTAL CORR	
BASETIME	
ZT OF SUN ________	
TWILIGHT CORR EVE (+30m) MORN (-45m)	
ZT OF TWILIGHT	
ZD (+W) (-E)	
GMT OF TWILIGHT	
GHA ARIES (hrs)	
GHA ARIES (m&s)	
TOTAL GHA ARIES	
DR LONG (+E) (-W)	
LHA ARIES	

PLANET INFORMATION

PLOT RIGHT ASCENSION (RA) AND DECLINATION OF PLANET

RA = 360° - SHA OF PLANET

BODY	VENUS	MARS
	3 6 0	3 6 0
SHA (-)		
RA		
DEC		
BODY	JUPITER	SATURN
	3 6 0	3 6 0
SHA (-)		
RA		
DEC		

BODY	AZIMUTH	ALTITUDE

1. SELECT TEMPLATE TO CORRESPOND TO DR LATITUDE.
2. PLACE TEMPLATE ON STARBASE TO CORRESPOND TO LATITUDE (NORTH or SOUTH).
3. SET ARROW ON TEMPLATE TO CORRESPOND TO LHA ARIES

INDEX

A

Acoustic Doppler, 84
Altitude, 89
Alidade,
  self synchronous, 15
  telescopic, 15
Anemometer, 28
Angles, 3
Aries, First Point of, 88
Astronomy, nautical, 85-93
  astronomical triangle, 91, 93, 109-116
  astronomy, 85, 86
  azimuth angle and azimuth, 90, 91
  celestial relationships, special 91-93
  celestial sphere concept, 87, 88
  horizon system of coordinates, 89-91
  motion, 85, 86
  navigational triangle, 91, 93
  time diagram, 89, 90
Automatic dead reckoning, 19, 20
Axis,
  definition of, 2
Azimuth,
  angle, 90, 91
  circle, 15
  definition of, 3, 90
  of Polaris, 129
  of sun, 127, 128

B

Barometer, 27
Bearing
  book, 64, 65
  circle, 15
  difinition of, 3
  radio, 66
  taking devices, 15, 16
  types of, 3
Binoculars, 28
Bow and beam bearings, 55
Buoyage, 62, 63

C

Celestial,
  fix, 112, 113
  horizon, 89
  lines of position, 109, 112, 113
  meridian, 87
  poles, 87
  sphere, 87
Celestial navigation, 100-129
  azimuths, 127-129
  general, 100, 101, 117
  local apparent noon, 94, 119, 120
  meridian sight, 117-119
  moonrise and moonset, 122, 123
  planet identification, 125, 126
  Polaris, latitude by, 120, 121
  sight reduction, 100-116
  star identification, 123-126
  sunrise and sunset, 122, 123
  twilight, 122, 123
Charts and projections, 29-39
  accuracy of, 39
  conic, 34, 35
  early, 29
  gnomonic, 33
  identification of, 36
  Mercator, 29-31
  plotting sheets, 31-33
  polar, 33, 34
  reading of, 39
  scale of, 36
  sources of, 35, 36
Chronometer, 24, 99
Circles,
  bearing, 15
  great, 2
  small, 2
Clocks, 24, 99
Coastal piloting, 133, 134
Comparing watch, 24, 99
Compass, 4-14
  adjustment, 10, 11
  comparison, 10, 12

Compass—Continued
  error, 9, 10, 53
  gyro, 4, 11-14
  magnetic, 4, 6-11
  rose, 9, 31, 32
Course,
  definition of, 3
  made good, 3
Culmination, 88
Currents, 42, 44-47
  consideration of, 47
  gravitation, 42
  introduction to, 42
  ocean, 44, 45
  tidal, 45-47

D

Danger angles and bearings, 57, 59
Dead reckoning, 1, 48-50
  analyzer-indicator, 19, 20
  current effect on, 49, 50
  definition of, 1
  plotting, 48, 49
  tracer, 19, 20
Decca, 76, 77
Declination, 87, 108, 109
Degaussing, 9-11
Depth, 3
Depth measuring devices, 21, 22
Deviation, 9-11
Deviation table, 9
Direction, 3
  compass, 6, 9, 10
  gyro, 12, 14
  magnetic, 10
  measuring devices, 15, 16
  true, 10, 12, 14
Distance, definition of, 3
Diurnal circle, 88
Drift, 49, 50
Dumb compass, 15, 16
Duties of navigator, 130-137
  coastal piloting, 133, 134
  detailed, 130, 131
  introduction, 130
  leaving and entering port, 131-133
  lifeboat navigation, 135-137
  navigation check-off lists, 131-133
  sea routine, 134
  ship's position report, 131, 134

E

Earth,
  definition of, 1, 2
  gravitational field of, 11
  magnetic field of, 4-6
Echo sounder, 22
Ecliptic, 87
Electronic navigation, 1, 22, 23, 66-84
  acoustic Doppler, 84
  advanced, 78-84
  basic, 66-77
  consol, 79
  consolan, 79
  decca, 23, 76, 77
  general, 66, 78
  inertial, 83, 84
  loran, 23, 69-76, 79
  marine radio beacons, 66
  omega, 79, 80
  radar, 22, 67, 68
  radio direction finder, 22, 66, 67
  radio receiver, 22
  ratan, 78
  raydist, 78, 79
  satellite system (NAVSAT), 80-83
  shoran, 69
  sonar, 22, 23, 69
  tacan, 69
Elevated pole, 87
Engine (shaft) RPM table, 19
Entering port, 131-133
Equator,
  definition of, 2
Equinoctial, 87
Equinoxes, 88

F

Fathometer, 22
Fixes, 48, 51, 52, 112, 113
Flashlight, 28

G

Gravitation, 11, 42
Greenwich hour angle, 87, 106-108
Gyrocompass, 4, 11-14
  comparison with magnetic compass, 12
  error, 12, 14
  general, 11
  principles of operation, 11, 12
  repeaters, 14
  systems, 14
Gyroscopic inertia, 4, 11

H

Hand lead, 21, 22
Hoey position plotter, 26
Horizon system of coordinates, 89-91
Hour circle, 87

I

Inertial navigation, 83, 84

L

Landmarks, 51-53, 61
Latitude,
  assumed, 110-113
  by meridian sight, 117-119
  by Polaris, 120-122
  difinition of, 2
  of the observer, 91
Lead, 21, 22
  deep sea, 22
  hand, 21, 22
Leaving port, 131-133
Lifeboat navigation, 135-137
Lights, 62, 63, 65
  predicting sighting of, 65
  sectors of, 65
  visibility of, 63, 65
Lines of position, 51-55, 58, 73, 74, 78, 109, 110, 112, 113, 117, 136
Local apparent noon, 117, 119, 120
Local hour angle, 87, 89, 90, 106-108
Logs, 16-19
  chip, 16, 17
  Doppler sonar, 19
  electromagnetic, 18
  impeller type, 18
  patent, 18, 19
  pitostatic, 17, 18
  rodmeter, 18
  taffrail, 18, 19
Longitude,
  assumed, 110-113
  definition of, 2, 3
  how to determine, 136
Loran, 23, 69-76, 79
  advantages and limitations, 73
  charts, 73, 74
  general, 69, 70
  interference, 72, 73
  loran-A, 69-76
  loran-C, 76
  loran-D, 79
  operation, 70-72, 74-76
  plotting procedures, 74, 76
  receivers, 70-76
Lubbers line, 8

M

Magnetic compass, 4, 6-11
  binnacle, 8
  bowl, 7
Magnetic compass—Continued
  card, 7
  comparison with gyrocompass, 12
  correction, 10
  designation, 6
  deviation, 6, 8-11
  expansion bellows, 8
  float, 8
  general, 4
  gimbals, 8
  lubbers line, 8
  magnets, 6, 7
  nomenclature, 6-8
  practical adjustment, 10, 11
  variation, 5, 6, 9, 10
Magnetism, 4-6
  earth's, 4-6
  ferrous metals, 4, 6
  fields of, 4-6
  induced, 4, 8, 11
  meridians of, 6
  permanent, 4
Maps, 29
Marine radiobeacons, 66
Meridian,
  angle, 88, 90, 91, 106-108
  definition of, 2
  prime meridian, 2
  sight, 117-119
Meridional parts, 33
Moon, rising and setting of, 122-123
Motion, 85, 86

N

Nadir, 89
Nautical slide rule, 26, 27
Navigation,
  basic definitions, 1-3
  duties detailed, 130, 131
  introduction to, 1-3
Navigational instruments, 15-28
  automatic dead reckoning, 19-21
  bearing taking devices, 15, 16
  binnoculars, 28
  celestial, 23, 24
  depth measuring, 21, 22
  electronic, 22, 23
  flashlight, 28
  plotting, 25-27
  short range measuring, 20, 21
  speed measuring, 16-19
  timepieces, 24, 25
  weather, 27, 28
Navigators case, 25

O

Ocean currents, 44, 45, 47
Omega, 79-81

P

Parallel rulers, 25
Parallel, defined, 2
Pencil, 25
Pelorus, 15, 16
Piloting, 1, 51-65, 130-134
  bearing book, 64, 65
  buoyage, 62, 63
  bow and beam bearings, 55
  compass error, 53
  danger bearings and angles, 57, 59
  doubling the angle on the bow, 55
  estimated position, 55, 56
  fixes, 51, 52
  introduction to, 51
  landmarks, 52, 53, 61
  lights, 63, 65
  light sectors, 65
  lines of position, 51-55, 58
  precision anchoring, 60, 61
  running fixes, 53-55
  soundings, in 56-58
  special cases, 55
  tactical characteristics in, 59, 60
  visibility of lights, 63, 65
Plotting instruments, 25-27
Plotting sheets, 31-33
Polar distance, 88
Polar distance of the zenith, 91
Polaris,
  azimuth of, 129
  latitude by, 120-122
Pole, definition of, 2
Port, leaving and entering, 131-133
Position plotter, Hoey, 26
Position report, ship's, 131-134
Precision anchoring, 60, 61
Prime meridian, 2
Prime vertical, 89
Protractors, 25-27
  parallel motion, 25, 26
  three-arm, 26, 27
Psychrometer, 28
Publications, 29, 39-41
  almanacs, 40, 41
  chart supplementary, 41
  manuals, 39, 40
  navigation tables, 40

R

Racon, 69
Radar, 67-69
  Accuracy, 68
  advantages and limitations, 67, 68
  beacons, 69
  fixes, 68
  principal parts of, 67
  virtual PPI reflectoscope, 68, 69
Radio direction finder, 66, 67
Ramark, 69
Range, 10, 51-53, 60
Ratan, 78
Raydist, 78, 79
Rhumb line, 3, 30, 33, 35
Right ascension, 88
Roller ruler, 25
Running fixes, 53-55

S

Satellite navigation system, 80-83
Sea routine, 134
Set, 49, 50
Sextant,
  altitude correction, 103-105
  marine, 23, 24, 101-103
  nomenclature, 101
Shoran, 69
Short range measuring instruments, 20, 21
Sidereal hour angle, 88, 89, 106, 107
Sight reduction, 100-116, 136, 137
  altitude intercept, 100, 109-113
  astronomical triangle solutions, 109-116
  celestial line of position, 110, 112, 113, 117, 136
  celestial fix, 112, 113
  declination, 108, 109
  greenwich hour angle, 106-108
  introduction to, 100, 101
  meridian angle, 106-108
  sextant altitude correction, 103-105
Solstices, 88
Sonar, 22, 23, 69
Special cases, 55
Speed,
  definition of, 3
  measuring devices, 16-19
Sperry gyrocompasses, 11-13
Stadimeters, 20, 21
Star identification, 123-126
Stop watch, 24, 25, 99
Sun, rising and setting of, 122, 123
Swinging ship, 10

T

Tacan, 69
Tactical characteristics, 59, 60
Telescopic alidade, 15
Thermometer, 27, 28
Tides, 42-44, 47
  consideration of, 47
  gravitation, 42
  tides and tables, 43, 44
Time, 94-99
  apparent, 94
  as related to arc, 97
  introduction to, 94
  mean, 94, 95
  measurement of, 94
  solar, 94-97
  sidereal, 97-98
  standard, 95
  time-pieces, 24, 25, 98, 99
  zones, 95, 96
Track, 3
Transit, 88
Twilight, 122, 123

U

Universal drafting machine, 26
Universe in motion, 85, 86

V

Variation, 5, 6, 10
Vertical circle, 89

W

Watches, 24, 25, 99
Weather instruments, 27, 28

Z

Zenith, 89
Zenith distance, 89
Zodiac, 87

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when new work is to be joined to it, the surface of the bricks must be cleaned and moistened.

Openings for branch sewers shall be made and junction pieces inserted in the main sewers in such manner and at such places as may be directed. Every junction piece shall be closed with a cover of earthenware, or with bricks and cement.

All brickwork will be measured and paid for by the cubic yard of solid wall.

TUNNELING.

In tunneling, the excavation shall be made so as to conform neatly to the regular section of the sewer, and nothing will be allowed for any excavation beyond this. All holes or irregularities outside of the regular section must be filled up solid with bricks and mortar, but no extra allowance will be made therefor.

All timbers used in sustaining the excavation must be removed as the brickwork progresses.

Points, by which to get the proper line of the sewer, will be given from time to time as may be needed, and from these the contractor will be required to continue the line of the excavation at his own risk of its accuracy, and to correct at once any errors of alignment that may be discovered before the brickwork is finished.

In tunnels, the quantities paid for will be the earth or rock excavated in the regular section of the sewer, and the brick or stone masonry required for this section, together with any foundation work that may have been expressly ordered, and the amount paid for these items shall be in full for furnishing all materials, and finishing the sewer; the cost of sinking shafts, pumping water, shoring, restoring falls and all accessory works of every kind being borne wholly by the contractor. Those parts only of the sewer will be paid for as tunnels, which are so marked on the plans exhibited at the time of the letting; all the rest will be paid for as open cut, regardless of the manner in which the work is actually done.

PIPE SEWERS.

All pipe sewers shall be made of the best quality of vitrified clay pipe with smooth interior surface. Each piece shall be straight or evenly curved, as may be required, and in section shall not vary more than half an inch from a true circle. The thickness of six-inch pipes shall not be less than three quarters of an inch; of twelve-inch pipes, not less than one and one eighth inches; of fifteen-inch pipes, not less than one and one quarter inches; and of eighteen-inch pipes, not less than one and one half inches. Junction pieces, for use in brick

sewers, shall be smoothly beveled off to an angle of forty-five degrees, and be not less than two feet long, exclusive of the socket. For pipe sewers the junction piece shall be a part of the main pipe, and no right angle junction shall ever be used.

So far as the specifications for the excavation of trenches, shoring and pumping, preparation of foundations, backfilling and restoring the street surface, already given for brick sewers, can be made to apply to the construction of pipe sewers, they shall be followed.

Each pipe is to be laid on a firm bed and in perfect conformity with the lines and levels given. The bottom of the trench must be shaped so as to fit the lower half of the pipe as nearly as possible, with places cut at the joints for the sockets to rest in, so that the pipe shall have a uniform bearing on the ground from end to end.

The pipes shall be joined by filling the socket with a mortar of pure cement without sand, with only water enough to give it a proper consistency. Great care must be taken to make the joint throughout the lower three fourths of the pipe perfectly water tight. The upper one fourth of joint, when so directed, shall be left open.

The interior of the pipes shall be carefully cleaned from all dirt, cement and superfluous material of every description, and a wad made of a sack filled with hay, large enough to fill the pipe and attached to a rod or cord, shall, at all times be kept in the pipe and drawn forward as the swork proceed, care being taken not to loosen the joints.

After the pipes are properly laid and joined, any space between them and the sides of the excavation must be filled with sand, either washed in or well rammed, up to the middle of the pipe. From this point for at least twelve inches above the top of the pipe, the earth shall be filled in so as not to disturb the pipes, and thoroughly rammed; after which, up to the surface, it may be either rammed in layers or thoroughly soaked with water, as may be directed by the sewer commissioner, so that the least possible settling will take place after the work is completed.

Pipe sewers will be paid for by the linear foot of finished work, the price so paid to be in full payment for furnishing and laying the pipe, including the earth excavation, shoring and pumping, backfilling, restoring the street surface, hauling away surplus material, and all other work and material required by the specifications or necessary to give a finished result.

Where rock is encountered in pipe sewers, such rock excavation shall be paid for at the price named herein————————————————————the amount to be estimated with

a base of six inches more than the inside diameter of the pipe and the side slope of one horizontal to eight vertical.

140. Specification for Sewer Pipe. The following specification for sewer pipe and specials is probably the most carefully worked out of any found in current American practice. While these specifications are very full and complete in many details which are usually overlooked, they are not unreasonably severe. They simply describe clearly what kinds of faults will serve as cause for rejection, and are as valuable to the manufacturer of the pipe in enabling him to select those specimens which he feels will be accepted, as to the inspector himself, who is called upon to accept or reject the material when supplied upon the ground. This specification, therefore, has the great merit of extreme definiteness of meaning, which is the most vital and necessary quality of all specifications. They were prepared by an engineer who knew from experience exactly what could be furnished by the best sewer pipe manufacturers without greatly increasing the cost.

Sewer Pipe and Specials—Pipe sewers are composed of straight sections which are herein termed "*pipe*," and of branches, bends, reducers, etc., which will here be called "*specials*" or "*special pieces.*"

The main sewer, as well as all surface and lot lateral sewers, shall be constructed of the best quality of salt-glazed, vitrified stoneware sewer pipe, and all special pieces that may be required in the work shall be of the same description and quality.

The pipes and specials must be carefully selected and examined by the contractor before or while being delivered upon the street, and all such material which may be used in the work must conform to the following requirements and conditions:

All hubs or sockets must be of sufficient diameter to receive their full depth the spigot end of the next following pipe or special without chipping whatever of either, and also to leave a space of not less than 1-8 inch in width all around for the cement mortar joint. Pipes and specials which can not be thus freely fitted into each other shall be rejected.

In the case of pipes and specials of 12 inches and upward in diameter, at least 40 per cent. of all such that will be used

in the work must be truly circular or substantially circular in cross-section; and in the case of pipes and specials less than 12 inches in diameter, at least 60 per cent. of the whole number required must be truly circular or substantially circular in cross-section. Of the remainder, in each case, the allowable divergence from a truly circular cross-section shall never exceed the following limits: *a.* For an *elliptical* cross-section, the greatest internal diameter must not be more than from 6 to 7 per cent. longer than the least internal diameter in the same cross-section. *b.* For an *oval or egg-shaped* cross-section, the same rule as for eliptical cross-sections shall apply. *c.* Pipes and specials having cross-sections which exhibit *angles*, *sharp curves* or *flat places* of appreciable magnitude in the circumference, will be rejected.

A single fire-crack, which extends through the *entire thickness* of a pipe or special, must not be over two inches long at the spigot end, nor more than one inch long at the hub or socket end, measured in the latter case from the bottom, or shoulder, of said hub or socket. Two or more such fire-cracks, however, at either end of said pipe or special will cause the same to be rejected.

A single fire-crack, which extends through only *two thirds of the thickness* of a pipe or special, must not be over four inches long at either end thereof, measured in the direction of its length. Two or more such fire-cracks, however, at either end of said pipe or special will cause the same to be rejected.

A single fire-crack, which extends through only *one half of this thickness* of a pipe or special, must not be over six inches long at either end thereof, measured in the direction of its length. Two or more such fire-cracks, however, at either end of said pipes or special will cause the same to be rejected.

A single fire-crack, which extends through *less than one half of the thickness* of a pipe or special, must not be over eight inches long, measured in the direction of the length of such pipe. Two or more such fire-cracks, however, anywhere in the pipe will cause the same to be rejected.

A transverse fire-crack in a pipe or special must not be longer than one sixth of the circumference of such pipe, nor shall its depth be greater than one third of the thickness thereof. Two or more such fire-cracks will be cause for rejection.

No fire-cracks of any description shall, however, be more than one eighth inch wide at its widest point.

No combination of the foregoing six limitations will be allowed, except with the express consent of the executive board and the city surveyor, as the intent and meaning of these restrictions or limitations is to insure the furnishing of the best marketable quality of pipe and specials by the contractor. In

general, any pipe or special which exhibits more than one fire-crack of the magnitudes above mentioned should be rejected at once by the inspector in charge of the work of laying the pipes, unless there be time to make a thorough aud minute examination of the other fire-cracks which it may display, and to become thereby convinced that they are of trifling significance.

Any pipe or special which is found to be cracked through its whole thickness from any other cause except the process of burning in the kiln, shall be rejected at once, regardless of the extent of such crack. This refers particularly to damage done by transportation, by cooling or by frost.

Irregular lumps or unbroken blisters on the interior surface of a pipe or special of sufficient size and number to form an appreciable obstruction to the free flow of the sewage, will be cause for rejection. A few small, unbroken blisters, not exceeding one fourth of an inch in height and one or two inches in diameter, upon the inner surface, need not reject a pipe or special. If there is a broken blister or a flake on the interior of a pipe or special which is thicker than one sixth of the normal thickness of said pipe or special, and whose largest diameter is greater than one twelfth of the inner circumferenc of said pipe or special, the latter shall be rejected. Furthermore, if such broken blister or flake is as large or smaller than just defined, then, unless said pipe or special can be properly fitted and laid so as to bring such broken blister or flake on the top or upper side of the sewer, the said pipe or special shall also be rejected.

Irregular lumps and small, unbroken blisters on the outside of a pipe or special need not reject it. A large and broken blister or a flake on the outside of a pipe or special, which is thicker than one sixth of the normal thickness of said pipe, and whose largest diameter is greater than from one ninth to one twelfth of the outer circumference of said pipe, will cause the same to be rejected. Should, however, the broken blister or flake be within the limits of size just defined, and should the pipe or special admit of being properly laid so as to bring said blister or flake on the upper part of the sewer, then said pipe or special may be accepted, if otherwise sound in all respects.

Any pipe or special which betrays in any manner a want of thorough vitrification or fusion, or the use of improper materials and methods in its manufacture, shall be rejected. Attention of inspectors is particularly called to the character of the material composing the interior of a pipe or special where the same is exposed by the breaking of a blister, the removal of a flake, or the face of the spigot end of such pipe.

All pipe and specials which are designed to be straight shall not exhibit any material deviation from a straight line

Special curves or bends shall substantially conform to the degree of curvature and general dimensions that may be required.

If a piece be broken out of the rim forming the hub or socket of a pipe or special without injuring the body of such pipe, the latter shall be rejected if the length of said broken piece, or the gap left thereby, is greater than one tenth of the circumference of said hub. In case that a defect of this nature, and within the limits just defined, occurs in a pipe or special, the latter shall also be rejected unless it can be so fitted in the sewer as to bring said defect on the upper part thereof.

The attention of the inspector in charge of the work of laying the sewer pipe is herewith particularly directed to the foregoing requirements as to the quality of the pipe and specials that will be allowed in the sewer, and in all cases of doubtful interpretation of said requirements, the necessary definitions will be given by the city surveyor and the executive board. Said board also reserves the right to add to the foregoing requirements, at any time during the progress of the work, such further restrictions and conditions respecting the quality of the said pipe and specials as it may deem for the best interests of the tax-payers, in order to secure the best materials which can practically be obtained. All such explanations or definitions of said requirements, in cases of doubtful interpretation, together with all said further restrictions and conditions relating to the quality of said pipe and specials, shall have the same force as though a part of this specification, and the contractor shall be required to comply therewith without extra compensation beyond the prices bid by him for performing the work.

E. K.

141. Specification for Laying Sewer Pipe. The following specification for the laying of sewer pipe and specials has all the merits ascribed to the specification for sewer pipe as given in the previous article, and has been prepared by the same engineer. For the purpose of removing any cement mortar which may have been forced through the joints, and which may, when hardened, form serious obstructions in the sewer, probably no specification will insure such excellent results as that given in the St. Louis specifications for pipe sewers in Art. 139, where the contractor is required to provide "A wad made of a sack filled with hay, large enough to fill the pipe and attached to a rod or cord, which

shall at all times be kept in the pipe, and which shall be drawn forward as the work proceeds, care being taken not to loosen the joints." It is an easy matter for the inspector to examine at any time to see whether or not this wad is being drawn forward, and when drawn forward it must of necessity remove any protruding fins of mortar, and leave the interior smooth and entirely free from such obstructions.

LAYING THE SEWER PIPE AND SPECIALS.—Previous to laying the pipe and specials which have been delivered upon the street, into the trench, they shall all be subjected to a rigid inspection by both contractor and inspector, and those which do not come up to the foregoing requirements shall be rejected.

Additional tests by sounding said pipe for cracks, and examining closely all blisters and flakes, shall also be applied. Before lowering the pipes and specials which have passed the inspections into the trench, they shall first be properly fitted together upon the surface of the street in the order in which they are to be used; and to facilitate the process of laying, the top of each pipe or special, after said fitting, shall be plainly marked with chalk or paint, so that the pipe previously laid in the bottom of the trench shall be disturbed as little as possible.

All pipes and specials in which the spigots and sockets can not be made to fit together, while on the surface, must be rejected, as no chipping of either socket, hub or spigot will be allowed.

The faces of all spigot ends and of all shoulders in the hubs or sockets must be true, and be brought into fair contact, and all lumps or excrescences on said faces shall be carefully cut away before the pipes are lowered into the trench.

In all cases where the rim of any hub or socket has been broken, as aforesaid, the pipe or special shall be rejected unless it can be so fitted as to bring the broken portion on the top, or upper portion of the sewer. The same condition shall also be applied to the case of broken blisters and flakes, as above mentioned, on either inside or outside of the pipes and specials. All special pieces required in the work, such as branches, bends, curves, reducers, etc., shall likewise be subject to the same conditions as the straight pipe.

The pipes and specials shall be so laid in the trench that after the sewer is completed the interior surface thereof shall conform on the bottom accurately to the grades and alignment fixed and given by the city surveyor. The main sewer will be divided by man-holes and lamp or hand-holes into a number of distinct divisions or working sections, in each of which the

grade and alignment shall, under ordinary circumstances, be truly straight. Changes of grade or direction, or both, in said main sewer will generally be made at man-holes or lamp or hand-holes, although under special conditions, to be defined only by the executive board and city surveyor, such changes may be made at intermediate places.

While the pipe and specials are being laid in each of the aforesaid straight divisions or working sections of the main sewer, a light or a burning lamp must be maintained continually by the contractor at the beginning of such section, and each pipe and specials must be so laid that such light or lamp shall remain constantly in plain view throughout the entire length of such section or division. The same test shall also be applied during the work of refilling the trench, so that when the sewer is in all respects fully completed and accepted by the executive board a light which may be applied at one end of such a division of the main sewer shall be clearly and plainly seen by looking through said sewer from the other end of said division or working section. The length of any such division or the distance between a man-hole and the next following lamp or hand-hole, or between any two consecutive openings of such kind in the main sewer, will, in general, not exceed 300 feet, although in particular cases it may be somewhat greater.

The trenches must, in all cases, be wide enough to admit of the laying of the pipe and specials as above mentioned, and wherever they have not been thus excavated, all necessary widening thereof must be done before the pipe and specials are lowered therein. Ample room or space must likewise be left on each side of said pipe and specials, both to admit of proper refilling underneath and also to allow of free access to all parts of the hub or socket while making the cement joint. Wherever any additional excavation or enlargement in the sides of the trench is required for such purposes, it shall be satisfactorily performed before the pipe and specials are laid or put into place, as no cutting away of the banks will be permitted after any such pipe or special has been set.

Furthermore, before any pipe or special is put into place, a small excavation must be made in the bottom of the previously graded trench to receive the projecting part of the hub or socket, so that each pipe will have a firm and uniform bearing upon said graded bottom over virtually its entire length. All adjustment of the pipes to line and grade must be done by scraping away or filling in the earth under the body of the pipe, and not by blocking or wedging up the spigot or the hub or socket. Special attention must be paid to this part of the work, since the stability and permanence of the sewer depend largely upon the manner in which the pipes are bedded.

The joints between the individual pipes and specials shall, in all cases, be made water-tight by completely filling out the entire annular space between the exterior of the spigot end and the interior of the hub or socket with hydraulic cement mortar, of such composition as is hereinafter specified. To prevent the mortar from reaching the interior of said pipe, the contractor may if he desires, use a narrow gasket of oakum or hemp, which shall be properly caulked into each joint, after which the mortar shall be introduced therein; but no extra compensation for the use of such gaskets will be allowed. Special care must be taken to secure a perfect filling of the aforesaid annular space at the bottom sides of the pipes, as well as at the top; and previous to the introduction of the mortar, said space, together with the surfaces of the pipe bounding the same, shall be thoroughly free all around from dust, sand, earth, dirt, small stones and water. After said space has been filled as described, a neat and proper finish shall be given to the joint by the further application of similar mortar to the face of the hub or socket, so as to form a continuous and even beveled surface, from the exterior of said socket to the exterior of the connecting spigot all around. The pipes must also be thoroughly cleaned before being laid; and any mortar, earth or other material which may have found its way through a joint or otherwise, into any pipe or special must be carefully removed before the next succeeding pipe is laid, in order that the interior of the sewer shall be left smooth and clean.

As soon as the cementing of any joint, whether in a main sewer or in a lateral sewer, has been completed, the excavation previously made in the bottom of the trench for the reception of the hub or socket must be carefully and compactly filled with sand, loam or fine earth, so as to hold the external mortar finish of said joint securely in its place; and such refilling shall also be carried up around the sides or circumference of the socket, as far as may be necessary. Any water which may have accumulated in said excavations must first be removed, or else said excavations must be completely filled out with the cement mortar specified, in which event no extra compensation will be allowed.

When a pipe or special is used in any main or lateral sewer, which is affected by a broken hub or socket, or a boken blister or flake, or a fire-crack on its exterior surface, as limited and defined in the foregoing, such pipe or special must be set so as to bring said permissible defect on the top or upper part of the sewer; and said defect must thereupon be completely and liberally covered over with a thick layer of hydraulic cement mortar, of the quality specified for the joints, to the full satisfaction of the city surveyor, and the executive board.

As the work proceeds, all of the required specials that are indicated upon the plan of the street, or that may be required during the progress of the work, shall be introduced and set in their proper positions.

Any omissions of the required specials intended to be laid, and indicated upon the plan for the sewer, or that may especially be ordered beforehand by the surveyor, shall be corrected by the contractor without additional compensation; but in case that any special not indicated upon the said plan, or not distinctly required to be introduced beforehand by the surveyor is inserted into the sewer after the latter has been laid, the expense of such insertions will be paid by the executive board upon proper certificate from said surveyor.

Before leaving the work for the night, or during a storm, or for any other reason, care must be taken that the unfinished end of the main sewer, or of any lateral sewer is securely closed with a tightly fitting iron or wooden plug. Any earth, or other material that may find entrance into said main sewer, or into any lateral sewer, through any such open end or unplugged branch, must be removed at the contractor's expense. The cost of all such plugs, and the labor connected therewith, moreover, must be included in the regular prices bid for the sewers. E. K.

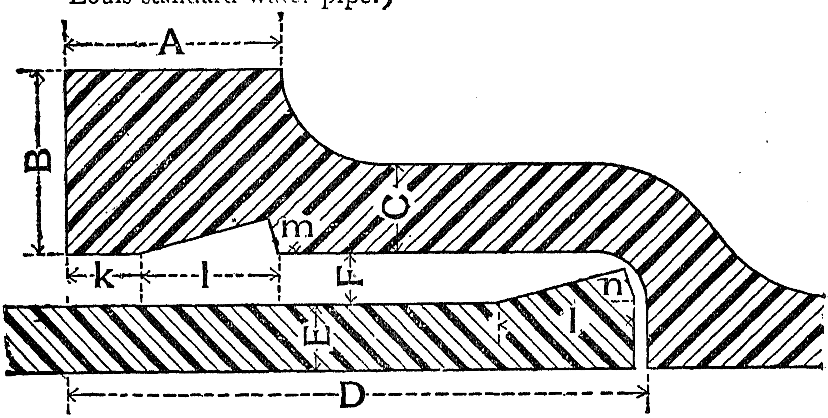
142. Specifications for the Manufacture and Delivery of Cast Iron Water Pipe. The following specifications for the manufacture of cast iron water mains are in use in the city of Rochester, N. Y. Although water pipe is now manufactured and sold as a standard article of commerce, and is often purchased without any test or inspection whatever, it must be admitted to be a poor practice, and if the contract is a large one, the material should be thoroughly inspected and tested in all the stages of manufacture. Special attention should be given to the tests of the strength and resilience of the material. When cast iron water mains burst, it is due to a water ram or shock, and the more elastic the material is of which the pipes are composed, the less will be the force of the ram the more able the pipes will be to withstand the shock. The resilience of the iron is measured by the product of the strength into the deflection, and in the following specifications both tensile and cross-breaking tests are required, and the

equisite deflection in the cross-breaking test is also specified. The deflection here named will insure a very good quality of cast iron, so far as its resilience is concerned, although the strength requirement is not particularly high. The author has had a large experience in testing the strength of cast iron, and he can approve of the standards of strength and resilience here named for water pipe metal.

Specifications for Water Pipe.

Dimensions and Weight of Pipe.—The pipe shall be of the kind usually known as "Hub and Spigot," and in general each straight pipe shall be about twelve feet in length from the bottom of the hub to the end of the spigot. No straight pipes will be received that will lay less than 11 feet 8 inches; but it is understood that not more than two per cent. of the total number of pipes required in each class may be 10 feet or more in length, produced by properly cutting off in a lathe a defectively cast spigot end. The form and dimensions of the hub and spigot ends of all pipes and castings shall be subject to the approval of the Engineer, when specific drawings therefor are not furnished by him, and shall conform accurately in shape and dimensions to all drawings that may be furnished by him from time to time.

(See accompanying figure for these dimensions for the St. Louis standard water pipe.)



The weights and dimensions of the straight pipes shall conform to the figures in the following Table, it being stipu-

lated that the same may be modified at any time hereafter by the Engineer:

TABLE OF WEIGHTS AND DIMENSIONS OF STRAIGHT PIPE.

Nominal internal diameter of pipe.	Class.	Thickness of barrel.	External diameter of Barrel.	Thickness of lead joint.	Depth of hub.	Standard weight of pipe laying 12 feet. Per lineal foot.	Standard weight of pipe laying 12 feet. Per pipe.	Permitted deviation in weight of pipe laying 12 ft.	Maximum weight of pipe laying 12 feet.	Minimum weight of pipe laying 12 feet.	Deduction from standard weight for each inch of less laying length than 12 feet.	Addition to standard weight for each inch of greater laying length than 12 feet.
in.		inches.	in.	inches.	in.	lbs.	lbs.	p. c.	lbs.	lbs.	pounds.	pounds.
36	A	1¼	38½	7-16 to ½	4½	492	5,904	3	6,081	5,727	51	41
36	B	1⅛	38½	7-16 to ½	4½	444	5,328	3	5,488	5,168	47	37
36	C	1	38½	7-16 to ½	4½	397	4,764	3	4,907	4,621	43	33
30	B	1	32¼	⅜ to 7-16	4½	330	3,960	3	4,079	3,841	35	26
20		¾		⅜ to 7-16	3¾	165	1,980	4	2,059	1,901	20	14
12		9-16		⅜ to 7-16	3½	75	900	4	936	864	8	6
10		½		5-16 to ⅜	3½	56	672	4	699	645	7	5
8		7-16		5-16 to ⅜	3¼	41	492	4	512	472	4	3
6		$\frac{27}{64}$		5-16 to ⅜	3¼	30	360	4	374	346	3	2

The specified internal diameter of the pipe is nominal, but no pipe or special casting of any class shall have a less internal diameter than the nominal diameter. The external diameters of all classes of said pipe shall be the same throughout, and all variations in thickness of metal of the shells or barrels shall be made by changing the internal diameter.

The thickness of the metal of the pipe and castings will be measured after they have been thoroughly cleaned, and before being coated. No pipe of any class will be received when the thickness of the metal is over one sixteenth ($\frac{1}{16}$) of an inch less in any part than the thickness above specified, or hereafter required by the engineer.

No pipe of full length will be received whose weight is less than the above specified minimum weight, and no excess of weight in any such pipe, beyond the specified maximum weight, will be paid for. It is also expressly understood that the average weights of the straight pipe of the several classes

shall not exceed the said standard weights by more than two per cent. of the latter, and that no greater over-weight than this percentage will be paid for in the final settlement. The standard weight of the straight pipes will depend upon the laying length of the pipes actually furnished, and will be determined by the engineer.

Quality of Metal.—The materials, details of manufacture, and the testing of all pipe and special castings herein referred to, shall at all times be subject to the inspection and approval of the engineer. The metal, which must be remelted in the cupola or air furnace, shall be made without admixture of cinder-iron or other inferior metal, and shall be of such character as to make a pipe strong, tough, and of sound, even grain, free from uncombined carbon when examined under the microscope, and such as will satisfactorily bear drilling, chipping and cutting. Its tensile strength and resilience, when tested in proper samples, shall meet all the requirements hereinafter expressed.

Specimen rods of the metal used, of a size and form suitable for a testing machine, shall be made and carefully tested to ascertain its tensile strength. Another set of test bars, each being twenty-six (26) inches long, two (2) inches wide, and one (1) inch thick, shall also be made as often as the engineer shall direct, and shall be tested both for transverse strength and deflection by placing them horizontally and flatwise upon supports twenty-four (24) inches apart, and then applying a steadily increasing load at the middle of each bar.

The bars for testing the transverse strength or resilience of the metal shall be cast from regular patterns in dry or green sand, and as nearly as possible to the required dimensions without being finished up; proper corrections will, however, be made in the results for slight variations of width and thickness. The rods for testing the tensile strength of the iron, on the other hand, must be turned down on a lathe in order to remove the rough exterior and enable the diameter to be accurately measured.

At least one set of four test bars, of each kind above designated, shall be made and tested as described on each working day during the manufacture of the pipes and specials. These test bars must be poured from the ladle either before or after any particular pipes or special casting are poured, and must present true samples of the iron used in said pipes or castings. Records shall be kept of the tests of all bars made, and a duly certified copy of such records shall be forwarded weekly to the engineer.

The quality of the metal used for the pipe and specials must be such that said bars for testing resilience, as aforesaid,

shall each carry a center load of not less than nineteen hundred (1,900) pounds before breaking, and exhibit a deflection of not less than five sixteenths ($\frac{5}{16}$) of an inch; also that the tensile strength of said metal shall be at least 17,000 pounds per square inch, as determined by the tests with the first named set of rods. In estimating the suitability of the metal from said tests, the average of the three highest results obtained from each set of four bars will be considered as representing the actual strength of the iron.

Manufacture of Pipe and Special Castings.—All the straight pipes shall be cast in dry sand moulds, vertically with the hub end down. Every pipe is to have the initials of the maker's name cast distinctly upon it, and also the year, the class letter, and a number signifying the order of its casting, in point of date; the several different classes of pipe each to have its own series of numbering; the figures and letters to be at least two inches in length, with a proportionate width; the weight of each pipe to be conspicuously painted on the outside, before delivery, with white lead paint at the contractor's expense.

The branches and all other special castings must conform in weight and thickness of iron to the drawings and directions to be furnished by the engineer, and no allowance will be made for making or altering patterns for the pipe or any special castings, or for any machine work in properly facing and drilling flanges, etc., where bolted joints are to be made. All required machine work on said castings shall be done in the best and most workmanlike manner, in accordance with said plans and directions of the engineer, and to his entire satisfaction. Said castings shall be subjected to the same examinations and tests at the foundry, except the water-pressure proof, as the straight pipe, and shall be marked in a similar manner. The engineer may reject, without proving, any pipe or casting which is not in conformity with the specifications or the drawings furnished.

Pipes and special castings shall not be taken from the pit and stripped while still showing any color of heat, but shall be left in the flasks for a sufficient length of time to prevent unequal cooling and contraction by subsequent exposure.

On being removed from the flasks, all pipes and special castings shall be subjected to a careful examination and hammer test for the purpose of detecting imperfections of any kind. They shall then be thoroughly dressed and made clear and free from earth, sand or dust, which adheres to the iron in the moulds; iron wire brushes must be used, as well as softer brushes to remove the loose dust. No acid shall be used in cleaning the castings. After having been properly dressed and cleaned, they shall again be subjected to a thorough inspection and hammer test. The contractor will be required at the

foundry to place all castings in such positions as may be deemed necessary by the Engineer for convenience of inspection.

The pipes and special castings shall be free from scoria, sand-holes, air-bubbles and other defects or imperfections; they shall be truly cylindrical in the bore, straight in the axis of the straight pipes, and true to the required curvature or form in the axis of the other pipes; they shall be internally of the full specified diameters, and shall have their inner and outer surfaces concentric. To insure proper diameters of sockets and spigots, a circular iron templet of the required dimensions shall be passed to the bottom of every socket, and a circular ring over every spigot. Care shall also be taken to avoid all excess in diameter of the sockets. No pipes or special castings will be accepted which are defective in joint room, whether in consequence of eccentricity of form or otherwise. No lump or rough places shall be left in the barrels or sockets, and no plugging or filling will be allowed. All pipes and special castings with defective hubs or flanges will be rejected.

When a defective spigot end is to be cut off from any straight pipe, such cutting must in all cases be done in a lathe, and a suitable bead or fillet of half-oval wrought iron, about three fourths ($\frac{3}{4}$) inch wide and five sixteenths ($\frac{5}{16}$) inch thick shall be shrunk upon the new end of the pipe; and there shall be deducted from the proper original weight of the pipe an amount as determined from the rate specified in the foregoing table.

Coating the Pipe and Special Castings.—After the above described cleaning and inspection, every pipe and special casting shall be heated in a suitable oven to a temperature of about 320° F. and, while at this temperature, be immersed in a bath of hot coal tar pitch varnish, prepared in general according to Dr. R. Angus Smith's process. Special care shall be taken to have the surfaces of all pipes and castings entirely clean and free from rust immediately before putting them into said bath. If any pipe or casting cannot be dipped in said bath soon after its removal from the mould, it shall at once be thoroughly coated with pure linseed oil in order to prevent the formation of any rust before applying said varnish.

The varnish above mentioned shall be made from coal tar, distilled until the naptha is entirely removed and the material deodorized, also until it attains the consistency of wax when cold. Pitch which becomes hard and brittle when cold will be rejected. To this material from five to six per cent. of its weight of pure boiled linseed oil shall be added and thoroughly boiled therewith. The relative portions of pitch and oil, as well as the details of mixture and boiling, are to be carefully determined by experiment.

The coating must be durable, smooth, glossy, hard, tough, perfectly water-proof, not affected by any salts or acids found in the soil, free from bubbles or blisters, strongly adhesive to the iron under all circumstances, and with no tendency to become soft enough to flow when exposed to the sun in summer, or to become so brittle as to scale off in winter. As one test of the quality of the coating, a properly coated specimen casting will be plunged into a freezing mixture, and kept therein until the metal has acquired the temperature of said mixture, after which the casting shall be well hammered. If the coating remains tough and adhering closely to the metal, it will be considered proper, provided that it be satisfactory in all other respects.

After a varnish of the proper quality has been obtained, it shall be heated in a suitable dipping tank to a temperature of about 300° F., or such other temperature as may be found expedient, and shall be maintained thereat uniformly during the time of dipping. Fresh materials must be added from time to time in the right proportions to keep the mixture of the proper consistency. The exact proportions will be determined by the Engineer, and will be varied also according to the season of the year, as may be directed by the said Engineer, or found necessary to produce a coating of the required quality. The tank shall also be occasionally emptied of its contents and refilled with fresh material, the frequency of such operation depending both on the character of the mixture and the manner of conducting the coating process.

Every pipe and special casting, after having been inspected, cleaned and dressed as above described, shall be heated in a suitable oven to a temperature about 20° F. higher than that which was found most expedient for the bath of coating material aforesaid, and while at such temperature, shall be immersed or dipped in said bath. All pipes or castings shall remain in the tank at least twenty (20) minutes, or as much longer as may be necessary to insure the soundness of the coating.

Whilst any pipe or casting remains in said bath, the hot mixture must be kept thoroughly stirred by a frequent rolling, turning or churning motion of such casting, and upon its removal from the tank, the coating shall fume freely for a short time, and set perfectly hard within one hour thereafter. Proper facilities for handling the castings and allowing all surplus material to drip off, shall be provided by the contractor. The cost of all labor and material involved in the coating of the pipes and castings must be included in the prices bid for furnishing said pipes and castings.

Testing.—After the said coating has become thoroughly set and hard, every pipe shall be subjected to a proof by water-

pressure of from 200 to 300 pounds per square inch, according to its class and diameter, and as will be determined by the Engineer. Each pipe while under the required pressure, shall be sharply rapped from end to end with a hand hammer, to ascertain whether any defects have been overlooked; and any pipes which may exhibit any defects by leaking, sweating or otherwise, shall be rejected.

All the above inspections, manipulation and tests of the pipe and test bars shall be made at the expense of the contractor for the pipe, said expense, however, not to include salary of any inspector who may be appointed by the Executive Board. If required by the said Board, the affidavit of the superintendent of the foundry, or that of the foreman employed by him to perform the above described testing, shall also be furnished to the Engineer from time to time; said affidavits to be recorded upon the pipe inspector's sheets, and stating in detail that the pipes or castings therein described have been carefully tested at the foundry in accordance with these specifications, and that no defects were discovered or discoverable.

Weighing for Payment.—The pipes and castings will be weighed for payment after all cleaning, dressing and machine work has been done and the coating has been applied, and the contractor must furnish, at his own expense, accurate and properly sealed scales, together with the necessary labor for the purpose. The Executive Board also reserves the right to re-weigh on similar scales, any pipe or casting upon or after its arrival at the designated point of delivery; and if any discrepency be discovered between the weight marked upon said pipe or casting and that which was found on such re-weighing, the latter weight will be adopted in the final settlement. Payment for all material furnished in accordance with these specifications will be made at the prices bid per net ton (2,000 lbs.) for straight pipe and special castings.

Transportation of Pipes and Castings.—All pipes and castings must be delivered in all respects sound and in conformity with these specifications. Upon their delivery at the point designated, the Executive Board reserves the right to subject the said pipe and castings to the same water-pressure proof and hammer tests as are above specified to be applied at the foundry; and all defective pipes or castings which may have passed the inspector at the foundry, or which may have been broken in transportation from the foundry to said point of delivery, will be rejected when there discovered, unless the same may be cut as hereinafter provided. Care must also be taken

in handling the pipes and castings not to injure the coating, and no material of any kind shall be placed in said pipes and castings during transportation, or any time after being coated.

If, upon its arrival at the designated point of delivery, the spigot end of any straight pipe should be found cracked or broken, during transportation from the foundry to the said point or otherwise, such defective portion will be cut off at the contractor's expense, provided that the same does not exceed a length of four (4) feet, and a suitable fillet or bead shall then be shrunk on the new spigot end, as above specified. A deduction from the proper original weight of such pipe shall also be made in each such case at the rate specified in the above table for every inch of length so cut off. No pipe or special casting in which the hub is found to be cracked or defective in any respect, will be accepted at said point of delivery or elsewhere; nor will any special casting with a defective spigot end be received, or permitted to be cut off, without the written order of the Engineer. E. K.

143. Specifications for Laying Water Pipe. The following clauses referring to the methods of laying water pipe, and making the joints, are taken from the complete specifications on this subject used by the water commissioner of St. Louis. All that portion of the specification referring to the trenching, protection, tools, alignment, grades, connections, back-filling, etc., together with the general clauses are here omitted.

The reducers, bends, caps and such other parts as are liable to draw, shall be firmly secured by straps and bolts, and in addition to this a firm blocking shall be set behind all caps, curves, fire hydrants and three way branches, said blocking to have a large surface bearing against the undisturbed earth, and to be wedged up tight. All applications necessary to the perfect working of the distribution, when the water is let on, shall be made and completed.

The straps and bolts used shall be made from the best American refined iron, and the size and workmanship, as well as the material, shall be in all respects satisfactory to the water commissioner.

Any omission of branches, stop-cocks, or other appurtenances intended to be laid, shall be corrected when required, by re-opening the trench, if it has been filled up, and introducing what may have been omitted.

At the time when laid, the spigots of the pipe shall be so adjusted in the sockets as to give a uniform space all around, and if any pipe does not allow sufficient space, it shall be replaced by one of proper dimensions. The joint shall, at all points, be at least five sixteenths of an inch in thickness. In the lead and gasket joints, the depth of lead shall not be less than three and one quarter inches for the fifteen inch pipes and over, nor less than two and three quarter inches for smaller pipes. Gaskets of clean, sound hemp yarn, braided or twisted, and tightly driven, shall be used to pack these joints, when required, a space of one quarter inch shall be left between the contiguous pipes.

The lead used shall be of the best quality of pure and soft lead, and suitable for caulking and securing a tight and permanent joint.

Before running the lead, the joints shall be carefully wiped out to make them clean and dry; the joint shall be run full at one pouring, and the melting pot shall always be kept within fifty feet of the joint about to be poured.

The joint shall be caulked by competent mechanics. The caulking to be faithfully executed, and in such a manner as to secure a tight joint without overstraining the iron of the bell. In all cases the caulking shall be done *towards* the place of the gate and other points where the lead is likely to be porous, so as to drive it together at these points. The lead, after being driven, shall be flush with the face of the socket.

The pipes and all other castings shall be carefully swept and cleaned, as they are laid, of any earth or rubbish which may have found place inside, during or before the operation of laying. Every open end of a pipe shall be plugged or otherwise closed before leaving the work for the night.

In refilling the trenches, the earth filled into the bottom of the trench, under and to the top of the pipes and other castings, shall be carefully packed and well rammed with proper tools for the purpose.

Whenever written directions so to do are given, the contractor shall fill the trench with river sand, said filling to be done in exact accordance with the orders and directions of the water commissioner. For all sand filling done as above, the sum of $ per cubic yard will be paid, which sum shall include all expense of materials, tools and labor for the sand filling, and removing the surplus earth from the work.

Care shall be taken to give the pipe a solid bearing throughout its entire length. The earth filling above the pipes shall

also be sufficiently packed and rammed to prevent after settlement, and the material used shall be free from stones or rock fragments. The trenches shall, in all cases; be refilled with the material furnished by their excavation, provided that it be of a proper quality, and the necessary haul be not more than 500 feet. Earth borrowed or hauled over 500 feet, to refill the trenches (excepting trenches where rock has been excavated), will be paid for as embankment, at the price given under item of section seven.

In streets and roads, the class of surface before existing, shall be replaced, so as to be in every way equal to that surface in materials and workmanship, and satisfactory to the water commissioner.

Whenever trenches are excavated in or across streets paved with granite or wood blocks, or with asphalt, the contractor will be required to have the back-fill of trench thoroughly rammed (not less than three men ramming to each man filling the trench), and to replace the paving temporarily, so as to make the street passible for traffic; the permanent laying of the pavement in these cases, will be assumed by the city.

A wooden box or vault shall be furnished and set over each of the stop cocks, air cocks, and fire hydrants, and the iron frames and covers shall be properly fastened to them. These boxes are to be made of the form and dimensions shown by samples furnished and approved by the water commissioner; they shall be made from sound, well seasoned oak lumber; the corner posts shall be of four-inch scantling, and the sides shall be formed from two-inch plank, set close, and securely nailed.

M. L. H.

144. Specifications for Stop Valves. The following specifications for stop valves for water mains are thought to be particularly strong in the requirements governing the strength of the material used in the different parts. These requirements are followed up very carefully by numerous tests of the strength of the material, and in this way the character of the composition metal used has come to be very superior to that formerly employed, and much superior to that which would be obtained without such rigid specifications and tests. They are the standard specifications used in the St. Louis water department.

All the iron castings shall be made from a superior quality of iron, remelted in the cupola or air furnace, tough and of even

grain, and shall possess a tensile strength of not less than 18,000 pounds per square inch.

Test bars of the metal 3 inches by ½ inch when broken transversely, 18 inches between supports and loaded in the center shall have a breaking load of not less than 1,000 pounds, and shall have a total deflection of not less than $\frac{3}{16}$ of an inch before breaking. Said bars to be cast as near as possible to the above dimensions without finishing, but correction will be made by the water commissioner for variations in thickness and width, and the corrected result must conform to above requirements.

Specimen bars of the metal used, of a size and form suitable for testing, shall be prepared when required.

These specimen bars shall be poured from the ladle at any time, either before or after the casting has been poured, as may be required, and shall present a true specimen of the iron used for making the castings.

If any two test bars cast the same day do not show the required cross breaking load and deflection, all the castings made from the same mixture to be rejected.

Each valve shall have the maker's initials, the numbers showing point in time of casting, and the year cast upon it. The year above and the number below, thus: $\frac{1890}{1}$, $\frac{1890}{2}$, etc.

The figures and letters will be from 2 to 2 ½ inches long, and shall have at least ⅛ inch relief.

All the wrought iron used shall be of the first quality of American refined iron.

All the composition metal used, except the valve stem, shall be composed of the following proportions, viz: 85 per cent. copper, 10 per cent. tin, and 5 per cent. spelter; and shall have a tensile strength of not less than 22,000 pounds per square inch, with 5 per cent. elongation in 8 diameters, and 5 per cent. reduction of area at breaking point.

All castings must conform in shape and dimensions to the drawings. The castings must be clean and perfect, without blow or sand holes, or defects of any kind. No plugging or other stopping of holes will be allowed.

The valve guides must be straight and smooth. Irregularities, if any, must be planed or chipped off smooth. All face joints must be planed true and smooth, in the most workmanlike manner, so as to make a perfectly water-tight joint, with a *very thin* layer of strictly pure lead cement.

All bolt holes must be accurately drilled from templates. The upper part of valve to be finished to receive the valve stem, collar and stuffing box, and the fitting at this point must be such as to secure a perfect working joint.

The valve to be a two-faced wedge valve; the castings for same to be as shown on drawing. The raised rims to be turned

true with dovetailed channel to hold the composition rings. The faces must be brought to the exact angle before the rings are put on. The face rings are to be of composition metal, of quality hereinbefore specified, and are to be turned to fit the dovetail in the iron wedge. The composition rings of valves must be shrunk on, and also fastened by copper studs, placed not over three inches apart—the whole to be then brought to a true plane surface.

The upper portion of the wedge to be arranged to receive the composition nut as shown. Care shall be taken to give the composition nut a perfect bearing surface—both top and bottom.

On the 36 inch and 30 inch valves, the brass bearings of side guides shall be of the full dimensions, and have the exact clearance shown on drawings, and be secured in place by countersunk copper studs, placed not over three inches apart, after which the guides shall be brought to a true and smooth surface.

The seats for rings in body of valve shall be turned true and smooth, and to the required angle as shown on drawings.

The seat rings shall be of form and dimensions as shown on drawings, and faced true and smooth. Seat rings to be forced into position and thoroughly and securely fastened in place, and a perfectly water-tight joint secured.

All valves of 10 inch diameter and upwards to be provided with indicator as shown on drawings.

All wrought iron bolts and nuts to be made from the best quality of American refined iron. The nuts to be hexagonal and the heads square. Heads, nuts and threads to be standard size.

Valve stem shall be made of phosphor bronze, quality B; or Crescent bronze, quality No. 2; or of first quality of "Stuckstede" bronze, and shall be free from flaws or defects of any kind, and have a tensile strength of not less than 30,000 pounds per square inch. Screw threads on the stems and nuts to be cut in most perfect manner, and of the exact pitch shown on the drawings, and so as to work true and smooth, and in perfect line throughout entire lift of valve.

There shall be two dowel pins, made of composition, set in the flanges connecting the dome and main casting, as shown on drawings, for the purpose of centering and bringing into perfect alignment these castings. Holes for dowel pins to be drilled and reamed tapering, and pins turned to perfect fit. Pins for the 36 inch and 30 inch to be 1 inch in diameter; for the 20 and 15 inch, 3/4 inch diameter; for the 12 and 10 inch, 5/8 inch diameter; and for the 8 and 6 inch, 1/2 inch diameter.

Gearing to be extra strong, and of the form and dimensions shown. Pinion post to be of a good quality of steel; key seats shall be truly cut, and keys made of steel, and of the full dimensions.

Cap nuts for valve wrench to be of the following outside dimensions: for all 6 to 15 inch valves (inclusive), to be 2 inches square; for the 20 inch, to be 2¾ inches square; and for the 30 and 36 inch, to be 3¼ inches square.

All iron work, after being thoroughly cleaned, to be painted with three good coats of paraffine varnish, applied hot. The valves shall be tested by hydraulic pressure, as follows:

First. Heads shall be secured at each end of casting, the valve opened, and a pressure of 200 pounds per square inch applied.

Second. Each face joint of valve shall be tested by closing the valve, leaving one end of the casting open, and applying a pressure of 100 pounds per square inch to the other—this operation to be reversed to test the other face.

Any and all defects developed in testing shall be thoroughly corrected to the satisfaction of the water commissioner. After testing all valves to be thoroughly drained.

All parts of valves of the same size to be perfectly interchangeable.

The water commissioner may take at random any wrought iron bolt or nut, and have it broken in a testing machine. If bolt shall not fulfill the requirements of table below, the whole lot of that size and make to be rejected:

Size of Bolt.	Tensile Breaking Strength.	Reduction of Area at Breaking Point.
5-8 inch.	9,000 lbs.	20 per cent.
3-4 "	13,000 "	20 per cent.
7-8 "	19,000 "	20 per cent.
1 "	25,000 "	20 per cent.
1 1-8 "	31,000 "	20 per cent.
1 1-4 "	40,000 "	20 per cent.
1 1-2 "	58,000 "	20 per cent.

The Water Commissioner may take at random any valve stem with nut, either finished or unfinished, for 6, 8, 10 or 12 inch valves, and have it broken in a testing machine.

If any stem or nut shall not fulfill the requirements of the table below, the whole lot of that make and size to be rejected.

Size of Valve.	Tensile Breaking Strength of Stem. (Including Nut and Collar.)	Ductility in 8 Diameter.
6 inch.	34,000 lbs.	8 per cent.
8 "	34,000 "	8 "
10 "	34,000 "	8 "
12 "	42,000 "	8 "

All valve stems for 15 inch and larger valves to be cast with a coupon on one end, 15 inches long by 1½ inches diameter. Any one or all of these coupons may be taken by the Water Commissioner and broken in a testing machine. If any coupon shall show a breaking strength of less than 30,000 lbs. per square inch, or shall have a ductility of less than 8 per cent. in 8 diameters, the stem from which it was cut shall be rejected.

For all materials taken by the Water Commissioner for testing which are found to conform to the above requrements, there shall be added to the final estimate:

For all wrought iron........................	7 cents per pound.
For all Phosphor bronze......	25 cents per pound.
For all Crescent bronze......	25 cents per pound.
For all Stuckstede bronze....	25 cents per pound.

The broken material to belong to the party of the second part. For all materials taken for testing which do not come up to requirements there shall be no allowance, and the broken material shall be returned to party of the first part.*

The whole to be put together in a thorough and workmanlike manner, and delivered, packed, ready for use. The working parts to be perfectly fitted together and working true in line. The joint between the face rings, when the valve is closed, must be absolutely water-tight. The whole to be in material, workmanship and finish, to the satisfaction and acceptance of the water commissioner. M. L. H.

LUMBER GRADING AND CLASSIFICATION.

145. Rules of the Southern Lumber Manufacturers' Association. The rules given in the following articles were adopted by the Southern Lumber Manufacturers' Association at Memphis, Tennessee, February 21, 1895. They are given here entire to assist the engineer to use descriptive terms in the same sense in which they are used by the lumber manufacturers and dealers. While they are intended to apply only to southern yellow pine, they can be understood to apply in a general way to all merchantable lumber. Since lumber is always sold under certain grade names, and since in the large

* In the St. Louis specifications the contractor is the party of the first part.

markets the lumber is officially graded, it is sufficient for the engineer and architect to use these technical terms in his specifications, provided he knows that he is using it in the same sense in which it is used by lumber dealers in that market. If he does not feel safe in limiting his description to the use of such technical class terms, he will still find considerable information in the following official rules, which will enable him better to describe the kind of lumber which he wishes to have supplied.

14[illegible]. General Rules for Classifying Lumber. The following general rules are intended to serve as a guide to lumber inspectors in enabling them to classify the lumber in accordance with the grades named below in subsequent articles.

1. Yellow pine lumber shall be graded and classified according to the following rules and specifications as to quality; and dressed stock shall conform to the subjoined table of standard sizes, except where otherwise expressly stipulated between buyer and seller.

2. * Recognized defects in yellow pine are knots (pin, round, spike, black, encased, loose or rotten), knot holes, splits (either from seasoning, ring-heart or rough handling), shake, wane, crooks, warp, rotten streaks, dote, rot, worm holes, pitch pockets, seasoning or kiln checks, blue sap and pitch streaks.

* Some of the following terms may need defining: Ring-heart is a "shake" or cleavage along the plane of an annual ring, usually about half way between the pith and the circumference. "Shake" or "wind shake" is a cleavage of the trunk of a tree while yet standing, due to the action of the wind in bending the trunk. It is usually along the plane of an annual ring, that is to say, concentric with the center or pith of the tree.

"Heart-shake" is a diametral or radial cleavage through the tree or log. If it occurs after the logs are cut, or in large timbers after they are sawed, it is due to shrinkage in drying. This is the common defect of all oak logs or large timbers.

"Wane" is a deficiency in width, either over the entire edge or on one corner, caused by a crook in the log.

"Crooks" are permanent distortions of the board, due to defective piling or from other causes.

"Warp" is a twisting of the board into a warped surface.

"Seasoning or kiln checks" are either very small or large cracks, caused by drying the surface of the board with its accompanying shrinkage, while the interior is still wet.

"Blue sap" is a discoloration, which green yellow pine is subject to, especially the sap portion, if not at once piled for drying or placed in a dry kiln.

"Pitch streaks" are longitudinal openings, sometimes of considerable size, as $\frac{1}{8}$ inch to $\frac{1}{4}$ inch wide and several inches (or even feet) long, filled with rosin.

3. Bright sap shall not be considered a defect in any of the grades provided for and described in these rules. The restriction or exclusion of bright sap constitutes a special class of material which can be secured only by specific contract.

4. Firm red heart shall not be considered a defect in common grades.

5. Defects in rough stock, caused by improper manufacture or drying, will reduce grade, unless they can be removed in working such stock to standard sizes.

6. Imperfect manufacture in dressed stock, such as chipped, grain splintered or torn places, broken knots on edge of shiplap, insufficient tongue on flooring, etc., shall be considered defects, and reduce grade accordingly.

7. A standard knot is sound, and not over 1¼ inches in diameter. A pin knot is sound, and not over half an inch in diameter.

8. Any piece that will not work one half its size shall be classed as a dead cull.

9. The grade of all regular stock shall be determined by the number and position of the defects visible in any piece. The enumerated defects admissible in any given grade are intended to be descriptive of the coarsest pieces such grade may contain. The average quality of the grade should be midway between such pieces and the defects allowed in the next higher grade.

10. Lumber or timber sawed for specific purposes, such as wagon tongues, bridge timbers, car sills, etc., must be inspected with a view to the adaptability of the piece for the use intended.

11. In finishing, flooring, etc., the enumerated defects admissible in a given grade apply only to the face side of the piece, but reverse face should not admit defects that would render the piece unsuitable for the purpose intended.

12. Standard lengths are multiples of 2 feet from 10 to 20 feet, inclusive, for boards and strips, and from 10 to 24 feet, inclusive, for dimension, joists and timbers. Longer or shorter lengths than those herein specified are special. Odd lengths, if below 24 feet, shall be counted as of the next higher even length.

13. On stock width shipments of 8-inch and under no board shall be admissible that is more than ¼ inch scant; on 10-inch not more than ⅜ inch, and on 12-inch not more than ½ inch scant of specified width.

14. Yellow pine of better grade than No. 1 common up to 4 inches in width is classified according to grain as edge grain and flat grain. Edge grain yellow pine has been variously designated as rift-sawn, straight grain, vertical grain and quarter-sawed, all being commercially synonymous terms.

Edge grain stock is specially desirable for flooring, and admits no piece in which the angle of the grain exceeds forty-five degrees from vertical, thus excluding all pieces that will sliver or shell from wear. Such stock as will not meet these requirements is known as flat grain.

15. All dressed and matched stock shall be measured and sold "strip count," *i. e.*, full size of rough strip from which such stock is made—3, 4, 5 and 6 inches wide.

16. The foregoing general observations shall apply to and govern the following detailed descriptive enumeration of recognized grades.

147. Rules for Grading Finishing Lumber. The following rules for grading apply to all kinds of finishing stock, whether for interior or out-door work. In these rules such expressions as "S. 1 S." or "S. 2 S." mean "surfaced one side," or "surfaced two sides," respectively. Also "S. 1 S. 1 E." will be understood to mean "surfaced one side and one edge." By surfacing is meant planing or running it through a planing machine. It may still require hand dressing for the best work. Nearly all saw mills now dry their lumber and run it through the planer, in order to save the extra freight on the rough and green lumber.

(Grades: First and second clear; third clear; barn and roofing stocks).

17. *First and Second Clear Finish*, 1 inch. S. 1 or 2 S., up to and including 10 inches wide, must show one face clear from all defects; 33⅓ per cent. of any shipment of 12 or 14 inches wide will admit two pin knots or one standard knot, slight pitch streak, or small pitch pocket, or sap stain not over 1½ inches wide running across the face, or small kiln or seasoning checks, but no two of these defects shall appear in a single piece; 16 inches wide will admit of two defects allowed in 12-inch or their equivalent. Wider than 16-inch will admit proportionately more defects. Pieces otherwise admissible in which the point of the grain has been loosened or slivered in dressing on the face side should be put in lower grade. Defective dressing or reverse face of finishing is admissible. In case both faces are desired clear special contract must be made.

18. *Third Clear Finish*, 1 inch, S. 1 S. or 2 S., up to and including 10 inches in width, may have not more than two, of the following defects on best or face side: Three pin knots one standard knot; three sap stains 2 inches wide running across

the face or their equivalent; two pitch pockets; slight pitch streaks, kiln or seasoning checks; torn places, and wane which does not enter more than 1 inch, nor extend more than 2 feet; 12-inch will admit three of the above defects, or their equivalent. This grade is suitable for paint finish.

19. $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 inch, S. 1 or 2 S., shall take 1 inch inspection, and unless otherwise agreed between buyer and seller, shall be subject to inspection on face or best side only.

20. Barn and novelty siding, shiplap and grooved roofing shall be 8, 10 and 12 inches wide, and consist of boards falling below third clear which are sound and water-tight, free from coarse knots and wane over 1 inch wide extending more than 3 feet in any piece. Pitch, except in narrow streaks, should be excluded.

21. *Edge-Grain Flooring*. (Grades: First clear, second clear). First clear edge-grain flooring must be well manufactured, and free from all defects on face side of strip.

22. Second clear edge-grain flooring will admit of three pin knots or one standard knot, or small pitch pocket, or blue sap stain not to exceed 10 per cent. of the face.

23. *Flat-Grain Flooring*. (Grades: A flat, B flat). A flat flooring may contain two pin knots or one small pitch pocket, but shall be free from other defects, and must be well manufactured. Pieces in which the point of the grain has been loosened in dressing should be put in lower grade.

24. B flat flooring may have any two of the following defects: Three pin knots or one standard knot, slight sap stains, small pitch pockets, slight torn places and defects in manufacture, narrow pitch streaks and seasoning checks. When all other defects are absent, blue sap stain in any quantity shall be admitted.

25. *Common Flooring*. (Grades: No. 1 common, No. 2 common). No. 1 common flooring must be manufactured from sound stock. In addition to the defects described in B flat, also admits of sound knots, blue sap and firm red heart in any quantity, pitch and slight shake, but must lay without waste. No division as to grain is made in this grade.

26. No. 2 common flooring includes all pieces that will not grade No. 1 common which can be laid without wasting more than one fourth the length of any piece. This grade will admit imperfections which do not render the piece unfit for use in cheap floors and roof sheathing.

27. Center-matched flooring shall be required to come up to grade on one face only.

28. *Ceiling*. (Grades: A, B, C). A ceiling shall be free from all defects on face side and well manufactured.

29. B ceiling will admit slight imperfections in dressing—three pin knots or one standard knot, pitch streaks or small pitch pockets, or blue sap stain not to exceed 10 per cent of the face; but not more than two of these defects to be admitted in any piece.

30. C ceiling conforms to grade of No. 1 common flooring and is suitable for paint finish. Will admit imperfections that do not prevent its use without waste.

31. *Wagon Bottoms.* (Grades: A, B). Wagon bottoms shall be graded the same as flat grain flooring.

32. *Bevel and Drop Siding.* (Grades: A, B and C). Shall be graded according to ceiling rules, but will admit more blue stain, and, except in C grade, should exclude pitch. Slight additional imperfections on the thin edge of bevel siding which will be covered by the lap are admissible.

33. *Partition.* (Grades: A, B and C). Partition shall conform to ceiling grades, but must meet the requirements of the specified grade only on one face. The reverse face shall not be more than one grade lower.

34. *Molded Casings and Base.* (Grades: First clear, second clear). First clear shall be free of all defects on face and perfect in manufacture.

35. Second clear is suitable for work that is to receive a paint finish, and usually consists of rejections, made after dressing, from stock inspected in the rough as first clear. The defects admitted in B ceiling would be allowed.

148. Rules for Grading Common Boards and Rough Lumber.

COMMON BOARDS AND SHIPLAP.

36. No. 1 common boards, S. 1 S., and No. 1 common shiplap shall be manufactured from sound stock, of even thickness the entire length. Will admit of any two of the following defects: Wane one half inch deep on edge and one sixth the length of any piece; tight sound knots, none of which shall be larger than three inches in diameter, or equivalent spike knots; one split not more than sixteen inches long, and blue sap. These boards should be firm and strong, suitable for use in all ordinary construction and serviceable without waste.

37. No. 2 common boards and No. 2 common shiplap admit pieces that fall below No. 1 common which are free from the following defects: Rotten streaks that go through the piece, through heart shakes which extend more than one half the length of the piece, and wane over two inches wide exceeding one third of the length of the piece. A knot hole 1½ inches in diameter or its equivalent will be allowed, provided the piece would otherwise grade No. 1 common. Worm

holes and straight splits one fourth of the length of the piece are admissible.

FENCING S. I S.

38. No. 1 common fencing must be manufactured from sound stock. May contain sound knots equal in diameter to not over one third the width of piece at any given point throughout its length, but must be free from spike knots the length of which is over one half the width of piece. Also, free from wane over one half inch deep on edge and one half the length of any piece measured on one side. This grade must work its full length without waste.

39. No. 2 common fencing shall admit of pieces that fall below No. 1 common which are free from through rotten streaks.

40. Miscut 1 inch stock in boards and fencing which does not fall below 3/4 inch thick shall be admitted in No. 2 common, provided that the grade of such thin stock is in all other respects as good as No. 1 common.

DIMENSION S. I S. I E.

41. *No. 1 Common Dimension* shall be manufactured from sound stock, and be free from loose and unsound knots, and large knots so located as to materially impair the strength of the piece; will admit of seasoning checks and heart shakes that do not go through, of slight wane and such other defects as do not prevent its use as substantial structural material.

42. *No. 2 Common Dimension* admits all pieces falling below No. 1 common which are free from through rotten streaks, and sound enough to be used without waste.

43. Miscut 2 inch stock which does not fall below 1 1/2 inch shall be admitted in No. 2 common, provided that the grade of such thin stock is in all other respects as good as No. 1 common.

44. In boards, fencing and dimension, stock falling below No. 2 grade and excluding dead culls shall be classed as No. 3.

45. Dressed timbers shall conform in grade to the specifications applying to rough timbers of similar size.

ROUGH YELLOW PINE—FLOORING STRIPS AND FINISHING.

46. Flooring strips are 3 inches, 4 inches, 5 inches and 6 inches wide when green; square-edged and evenly manufactured.

47. Finish must be evenly manufactured, and shall embrace all sizes from 1 inch to 2 inches thick by six inches and over in width.

48. No finishing lumber, unless otherwise ordered, should measure when dry and rough less than $\frac{1}{16}$ inch scant in thick-

ness. No piece in any shipment of boards and strips shall be more than $\frac{1}{4}$ inch scant on 6 and 8 inch stock, $\frac{3}{8}$ inch scant on 10 and $\frac{1}{2}$ inches scant on 12 inch and wider stock.

49. Wane and seasoning checks that will dress out in working to standard thicknesses and widths are admissible.

50. Subject to the foregoing provisions rough finishing shall be graded according to the specifications applying to dress finishing. When like grade of both faces is required special contract should be made.

COMMON BOARDS, FENCING AND DIMENSION.

51. *Rough Common Boards and Fencing* must be evenly manufactured, and should not be less than $\frac{7}{8}$ inch thick when dry, nor more than $\frac{1}{2}$ inch scant of specified width.

52. *Rough 2 inch Common* shall be evenly manufactured and not less than $1\frac{7}{8}$ inches thick when green, or $1\frac{3}{4}$ inches thick when dry. The several widths must not be less than $\frac{1}{8}$ inch over the standard dressing width for such stock.

53. The defects admissible in rough rock shall be the same as those applying to dressed stock of like kind and grade, but such further defects as would disappear in dressing to standard size of such material shall be allowed.

54. Rough timbers 6x6 and larger shall not be more than $\frac{1}{4}$ inch scant when green and be evenly manufactured from sound stock with not less than three square edges, and must be free from knots that will materially weaken the piece.

55. Timbers 10x10 in size may have a 2 inch wane on one corner, or its equivalent on two or more corners, one fourth the length of the piece. Other sizes may have proportionate defects.

56. Seasoning checks, and shakes extending not over one eighth the length of the piece, are admissible.

149. Standard Dimensions of the Southern Lumber Manufacturers' Association.*

Flooring. The standard of 1x4 and 6 inch shall be $\frac{27}{32}$x$3\frac{1}{4}$ and $5\frac{1}{4}$ inches; $1\frac{1}{4}$ inch flooring, $1\frac{3}{32}$ inches.

Ceiling. $\frac{3}{8}$ inch ceiling, $\frac{5}{16}$ inch; $\frac{1}{2}$ inch ceiling, $\frac{7}{16}$ inch; $\frac{5}{8}$ inch ceiling, $\frac{9}{16}$ inch; $\frac{3}{4}$ inch ceiling, $\frac{11}{16}$ inch; same width as flooring.

Finishing. 1 inch, S 1 S or S 2 S, to $\frac{27}{32}$; $1\frac{1}{4}$ inch, S 1 S or S 2 S, to $1\frac{3}{32}$ inch; $1\frac{1}{2}$ inch, S 1 S or S 2 S, to $1\frac{11}{32}$ inches; 2 inch, S 1 S or S 2 S, to $1\frac{3}{4}$ inches.

Boards and Fencing. 1 inch, S 1 S or S 2 S, to 13-16.

*These particular dimensions can not be assumed to hold for all parts of the country.

Dimension. 2x4, S 1 S 1 E, to 1⅝x3⅝ inches; 2x6, S 1 S 1 E, to 1⅝x5⅝ inches; 2x8, S 1 S 1 E, 1⅝x7½ inches; 2x10, S 1 S 1 E, to 1⅝x9½ inches; 2x12, S 1 S 1 E, to 1⅝x11½ inches; 4x4, ⅜ inch off side and edge; 4x4, S 4 S, ¼ inch off each side.

149a. Rules Governing the Inspection and Measurement of Lumber in the St. Louis Market.

RULE 1. Standard grades of lumber shall be firsts and seconds, common, and cull. In the grade of firsts and seconds the purchaser is entitled to a fair proportion of clear lumber, which must not be less than 33⅓ per cent. First and clear are interchangeable terms meaning that the lumber must be 6 inches wide and over, except poplar, yellow pine and cypress, which must be 8 inches wide and over, and free from all defects.

RULE 2. Standard lengths shall be 10, 12, 14, and 16 feet. The first and second grade will admit nothing under 10 feet and not to exceed 10 per cent of 10 feet in any lot; *i. e.*, 10 per cent of all 10-foot lumber in any lot may be graded as firsts and seconds. In black walnut, cherry, and hickory an exception is made, and the total amount of 10-foot lumber may be graded as firsts and seconds. An exception is also made in ash, in which 18 feet or longer, and in quarter-sawed lumber 10 per cent of the entire lot may be graded as firsts and seconds. Shorter and longer than standard lengths in all varieties of hardwood lumber are to be reduced in grade unless otherwise agreed between buyer and seller, in which case it shall be so stated in the certificate of inspection.

RULE 3. Standard thicknesses shall be 1, 1¼, 1½, 2, 2½, 3, 3½ and 4 inches, except poplar, which will allow ½, ⅝ and ¾ inches in car lots.

RULE 4. Standard knots shall not exceed 1¼ inches in diameter and must be of sound character.

RULE 5. Lumber must be sawed into plump and even thicknesses. Scant-sawed lumber must be reduced to the next standard thickness, and in case of 1-inch lumber to one grade lower. All badly sawn, miscut, and uneven lumber shall be classed as cull, except when such will dress to its full length and width in the next standard thickness, in which case the piece shall not be reduced in grade.

RULE 6. Splits are always more or less damage to a piece of lumber. An allowance must be made in determining the quality or quantity, according to the nature of the split. A straight split extending not to exceed the width of the board in length shall be admitted into the grade of firsts and seconds.

RULE 7. A cull which will not work one half its size without waste is a mill cull of no recognized value.

RULE 8. Lumber sawed for specific purposes, such as axles, bolsters, tongues, reaches, newels, balusters, squares, etc., must be inspected with a view to the adaptability of the piece for the intended use, as in many cases it can not be used for other purposes.

RULE 9. Merchantable lumber is lumber measured for what it will work.

RULE 10. Log run is the entire cut of the log, mill culls out.

RULE 11. It is important that all lumber shall be parallel in width, square-edged, and with square ends.

Tapering lumber shall be measured one third the length from the small end.

RULE 12. Ordinary season checks are not considered defects. Black stain, heart shakes, rots, wormholes, and dote are considered serious defects, reducing to a grade lower than firsts and seconds.

RULE 13. The inspection grades of wagon stock, newels, balusters, and table-legs shall be good and cull.

RULE 14. Newels from all kinds of timber must be clear and free from heart, to square 5, 6, 7, 8, 9, and 10 inches plump. The lengths must be 4 feet full, or multiples thereof.

RULE 15. Balusters and table-legs shall be clear and square 2x2, 2½x2½, 3x3, and 4x4, 30 and 32 inches long.

RULE 16. Bolsters must be 4 feet and 4 feet 6 inches in length, and the size must be 3x4, 3½x4½, 4x5, 4½x5½, and 5x6.

RULE 17. Reaches must be 2x4, 8, 9, and 10 feet, or 2¼x4½, 12, and 16 feet long.

RULE 18. Hickory axles shall be 6 feet for 3x4, 3¼x4¼, 3½x4½, and 4x5 inches, and 6½ feet long, for 5x6 and 5x7.

RULE 19. Wagon tongues must be straight and 2x4 at the small end, and 3x4, 3½x4, or 4x4 at butt end, 12 feet long.

POPLAR.

The inspection grades shall consist of *firsts* and *seconds*, *common*, and *cull*.

Firsts and Seconds shall be 8 wide inches and over; at 8 inches will admit of 1 inch of bright sap, but no other defects; at 10 to 12 inches will admit of 3 inches of bright sap, or two standard knots; at 12 to 15 inches will admit of 4 inches of bright sap and two standard knots, or three standard knots if there is no sap.

Boards and plank free from other defects may be one half bright sap if over 12 inches wide.

Common shall include any width not less than 6 inches, and will allow of bright or discolored sap and knots beyond those described in firsts and seconds. Two unsound standard knots will be allowed in this grade if over 12 inches wide, and splits shall not be considered a defect. Otherwise the lumber must be sound.

Culls shall comprise all widths and sizes having more defects than described in common, whether in the number or in the character of the knots, badly checked, and generally such lumber as is unfit for ordinary purposes.

Box boards shall be 12, 14 and 16 feet long, from 13 to 17 inches wide, free from all defects except bright sap.

Poplar strips shall be full 6 inches wide, 1, 1¼, and 1½ inches thick, 12, 14, and 16 feet long. Clear shall be free from all defects. Second clear may be one half bright sap on one side and have one sound knot not over ¾ of an inch in diameter. Common shall embrace all sound strips with more defects than second clear. Cull shall contain all unsound strips that will work one half its contents, and all tapering strips.

Poplar squares shall be graded No. 1, No. 2, and culls.

No. 1. Lengths may be 8, 9, 10, 12, 14, 16, and 18 feet. 4x4 will admit one half inch bright sap, or two standard knots. 5x5, 6x6, and 7x7 will admit one third bright sap or two standard knots. 8x8, 10x10, and 12x12 will admit one half bright sap and three standard knots.

No. 2 will admit colored sap knots of a sound character, wane, ordinary season checks, and splits not to exceed 12 inches in length.

Cull shall comprise all squares below the grade of No. 2.

ASH.

Firsts and Seconds must be 6 inches wide and over. At 8 inches one and at 10 inches two standard knots, or their equivalent in other defects may be allowed. An allowance for more defects of this character may be made in proportion to increased width. Eighteen feet or longer must be 5 inches or over wide.

Common shall include 5 inches and over wide. At 6 inches one, and at 8 inches two standard knots, or their equivalent in other defects, may be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Cull shall comprise all widths and sizes below the description of common.

OAK.

Firsts and Seconds must be 6 inches wide and over. At 8 inches one, and at 10 inches two standard knots, or their equivalent in other defects, may be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Common shall include 5 inches and over wide. At 6 inches one, and at 8 inches two standard knots, or their equivalent in other defects, may be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Dimensions may contain sound hearts if well boxed. Heart shakes, rot, and dote are not admissible.

Cull shall comprise all widths and sizes below the description of common.

YELLOW PINE.

Finishing 1 to 2 inches.

The inspection grades shall consist of *firsts* and *seconds* *common* and *cull*, and shall be inspected on best face.

Firsts and Seconds must be 8 inches wide and over; up to and including 10 inches wide will admit two sound knots not over ¾ of an inch in diameter; at 12 inches will admit three sound knots not over ¾ of an inch in diameter, or one standard knot. An allowance for more defects of this character may be made for increased widths. Bright sap is not considered a defect.

Common shall include all lumber not up to the grade of firsts and seconds, but free from shakes, large knots or unsound lumber.

Culls shall comprise all lumber below the description of common.

Strips shall be 4 inches and 6 inches wide.

Firsts and Seconds must be free from all defects on one side. Bright sap is no defect.

Common may have three small knots not more than ¾ of an inch in diameter, or one standard knot, blued sap or small wane on one edge which will not injure it for working to its full size.

Culls shall comprise all lumber below the description of common.

QUARTER-SAWED HARDWOOD LUMBER—OAK, SYCAMORE, ETC.

Firsts and Seconds must be 6 inches wide and over. At 7 inches one, and at 9 inches or wider two standard knots will be allowed.

Common shall be 3 inches and over wide. At 6 inches one, and at 8 inches two standard knots, or their equivalent in other defects, will be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Culls shall comprise all lumber below the description of common.

QUARTER-SAWED OAK STRIPS.

Quarter-sawed oak strips shall be 3, 4, and 5 inches wide, and the inspection grades shall be *firsts* and *seconds* and *cull.*

Firsts and Seconds shall have one face clear of all defects. *Cull* shall include all lumber not up to the grades of firsts and seconds.

BLACK WALNUT, CHERRY, BUTTERNUT AND CHESTNUT.

Firsts and Seconds must be 6 inches and over wide. At 8 inches one inch of sap or one standard knot, and at 10 inches two inches of sap or two standard knots may be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Common shall be 5 inches and over wide and shall include all lumber not up to the grades of firsts and seconds, but available fully ¾ its size without waste, free from hearts and un-

sound lumber. Heart shakes, rot, dote, or worm-holes are not admissible.

Culls shall comprise all lumber below the description of common.

NOTE.—Gum spots are considered a serious defect, and when their damage exceeds one-sixth of the size of the piece, shall reduce the grade to common. When their damage exceeds one-third the size of the piece, it shall be reduced to cull.

CYPRESS.

Firsts and Seconds must be 8 inches and over wide, and clear up to 10 inches; at 10 to 12 inches may have two standard knots and 3 inches of bright sap. An allowance for more defects of this character may be made in proportion to increased width. Free from other defects may be one half bright sap. Lengths of 18 feet and over are allowed in this grade.

Common will contain all lumber under second class, and all shaky lumber that is available three-fourths.

Culls shall comprise all lumber below the description of common.

GUM.

Firsts and Seconds must be 6 inches wide and over. At 8 inches may have one standard knot, and at 10 inches two standard knots; 10 to 12 inches may have three standard knots. An allowance may be made for more defects of this character in proportion to increased width. Sap not admitted in this grade.

Common shall include all lumber available for use full three-fourths its size without waste, free from hearts and unsound lumber. Bright or slightly discolored sap may be included in this grade.

Culls shall comprise all widths and sizes below the description of common.

BIRCH.

Firsts and Seconds must be 6 inches wide and over. At 8 inches one, and at 10 inches two standard knots, or their equivalent in other defects, may be allowed. An allowance for other defects of this character may be made in proportion to increased widths. Seventy-five per cent of the face must be red.

Common shall be sound 5 inches and over in width, and may have defects not injuring it for ordinary use without waste. At 6 inches one, and at 8 inches two standard knots, or their equivalent in other defects, may be allowed. An allowance for more defects of this character may be made in proportion to increased width.

Culls shall comprise all widths and sizes below the description of common.

HICKORY, PECAN, HARD AND SOFT MAPLE, ELM, BEECH AND SYCAMORE.

To these the standard rules governing Ash are applicable.

RULE FOR MEASURING LOGS.

All logs measured by the authority of this Exchange shall be measured by Scribner-Doyle's Rule, as published in Scribner's Lumber and Log Book.

150. Specification for Thoroughly Seasoned Lumber. There is no difference between "seasoned" lumber and "dried" lumber. "Thoroughly seasoned" or "thoroughly dried" lumber is lumber which has been dried, either in the open air or in a dry kiln, until it has reached that state of dryness which is relatively permanent. It then contains water equal to about ten per cent. of its weight. This is what might be called the atmospheric moisture. This will remain in the wood unless driven off by evaporation at a temperature of 212 degrees Fahrenheit or more. The word "thoroughly" when used in this connection, means "uniformly" as well as "effectually." That is, "thoroughly dried" lumber is dried uniformly throughout its entire cross-section and throughout its entire length.

To determine the percentage of moisture of lumber it is only necessary to cut a section from a board or stick and weigh it; then dry in an ordinary stove oven with a slow fire for an hour or two and then weigh again; the difference in weight divided by the dry weight is the percentage of moisture. As determined by this test, "thoroughly dry lumber" should not contain more than ten or twelve per cent. of water, and the interior should be as dry as the exterior.

The necessity for using thoroughly dried lumber where shrinkage is to be avoided, arises from the fact that *below about 30 per cent. moisture lumber shrinks nearly as much as it dries.* That is to say, when lumber dries down from 30 per cent. moisture to 10 per cent. moisture it dries out, or loses in weight, 20 per cent. of its dry weight. It also loses about 20 per cent. of its dry volume, or say 15 per cent. of its volume at 30 per cent. moisture. The shrinkage lengthwise is very slight,

hence it has lost about 15 per cent. of its cross-section, or say six or seven per cent. of each of its lateral dimensions. That is to say a board one foot wide at 30 per cent. moisture is only about 11⅜ inches wide at 10 per cent. moisture; or a flooring board 4 inches wide at 20 per cent. moisture is only about 3¾ inches wide at 10 per cent. moisture. On account of the very large radial fibres (medullary rays) in oak wood, this kind of lumber shrinks mostly in a circumferential direction, and all timber shrinks more circumferentially than radially since all woods have these medullary rays to a greater or less extent. It is for this reason that "quarter sawed" (radial sawed) lumber is more satisfactory than "flat sawed" for all kinds of furniture and house trimmings. For flooring quarter sawed, or "rift sawed" boards, presenting an "edge-grain" surface, is far preferable to "flat-grain" because it wears evenly and does not sliver on the surface.

The specification may read as follows:

All the lumber delivered under this contract, to be used for purposes of ————, shall be thoroughly seasoned or dried, either in the open air or in a kiln or both. By "thoroughly seasoned" as here used is meant a seasoning or drying uniformly throughout the entire sections of the various sizes delivered, and the average percentage of moisture contained in the lumber when delivered shall not be more than ten per cent. of its weight, as determined by actual experiment.

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151. Specification for Cast Iron.* There is probably no material in engineering structures which can more profitably be governed by specifications involving tests than cast iron. Since cast iron usually breaks under some kind of shock or blow, it is more necessary to test the iron for resilience than for strength. The most convenient test for resilience is

* See the author's *Materials of Construction* for a full description of methods of manufacture, methods of testing, and physical properties of all the metals commonly used in engineering works.

the cross-bending test, in which deflection is measured. The half product of the deflection multiplied by the breaking load is the mathematical measure of the resilience in inch pounds. This can be reduced to an absolute unit by dividing by either the weight or the volume of the bar, and if all the bars tested in this way are rectangular in cross-section and of uniform size from end to end, the unit obtained in the above manner will be comparable, notwithstanding great variations in the dimensions. It is best, however, to have the test specimens always made from the same pattern, using the thickness of metal which corresponds closely to the average thickness of web of the castings required. If uniform test specimens be employed, there is no necessity of dividing the half product of deflection and breaking load by the volume or by the weight, since this volume or weight remains a constant. In this case the relative resilience of the material will be indicated by the product of the breaking load into the maximum deflection. The *strength* of the material will be indicated by the breaking load alone.

The following specification is the one commonly employed for all castings made for the water department of St. Louis, and is designed to answer the above requirements.

Cast Iron.

All of the iron castings shall be made from a superior quality of iron, remelted in the cupola or air furnace, tough and of even grain, and shall possess a tensile strength of not less than 18,000 pounds per square inch.

Test bars of the metal 3 inches by ½ inch, when broken transversely, 18 inches between supports, and loaded in the center, shall have a breaking load of not less than 1,000 pounds and shall have a total deflection of not less than 3-10 of an inch before breaking.* Said bars to be cast as near as possible to the above dimensions without finishing; but correction will be made by the water commissioner for variations in thickness and width, and the corrected result must conform to above requirements.

*The tensile strength may be raised to 20,000 or even to 25,900 pounds per square inch, while the deflection may be made ⅜ inch for ordinary good cast iron and ½ inch for a better quality. For a superior quality it may be made ⅝ inch, with a breaking load of 1250 pounds.

Specimen bars of the metal used, of a size and form suitable for testing, shall be prepared when required.

These specimen bars shall be poured from the ladle at any time, either before or after the casting has been poured, as may be required, and shall present a true specimen of the iron used for making the castings.

If any two test bars cast the same day show a breaking strength of less than 18,000 pounds per square inch, or do not show the required cross-breaking load and deflection, all the castings made from the same mixture to be rejected.

All castings shall conform to the shape and dimensions required by the drawings, and shall be clean and perfect, without blow or sand holes, or defects of any kind. No plugging or other stopping of holes will be allowed.

Particular care shall be taken to secure perfect lugs, where such are required by the drawings. Whenever any doubt exists of the exact interpretation as to the shape or dimensions shown on the drawings, the contractor must consult with the water commissioner, or his duly authorized agent, in regard thereto.

M. L. H.

152. Specification for Cast-Iron Water Pipe.

The following specifications for cast-iron water pipe were used in the contract of the new water works system of Cincinnati (1900–1902). Special attention is called to provisions Nos. 14 and 15. It is well known that the coal-tar coated cast-iron water pipe will rust more or less on the outside and will form numerous "tubercles" of iron rust upon the interior. This rusting action is certainly due to imperfect coating and this in turn is doubtless due to the iron scale and other foreign matter left on the outside of the casting when dipped into the bath of coal-tar varnish. It is now well known that no perfect protection of iron by painting when exposed to the weather, is effective unless the iron has first been entirely freed from rust and the ordinary oxide coating which it has when it comes from the rolls. The sand blast is the only perfect means of cleaning the iron from this oxidized coating. This sand blast method of cleaning water pipes is provided as an alternative by provision 14 below, and was, with much difficulty, forced upon

the contractors. The author believes this to be the only absolute assurance against exterior rusting and the forming of tubercles upon the interior of cast-iron water pipe. Methods can be devised for applying this method of cleaning to the interior as well as to the exterior of such pipes. This would not only greatly extend the life of the pipe but it would preserve its original efficiency as a water carrier. The cost of this method of cleaning the pipes would be a very small percentage of the total cost of the works but would add largely to the life and efficiency of that part of the system which represents three-fourths of the total cost.

1. The iron shall be of pig metal, properly selected and compounded to obtain the desired quality. It shall be a tough, gray metal; close, even grained; uniform in quality; soft enough to permit drilling and cutting, and capable of showing indentations from a sharp blow of a hammer without flaking. When tested in specimens one inch in diameter, from which the skin has been removed by turning, all metal used shall stand, without breaking, a tensile stress of not less than 20,000 pounds per square inch. Cast bars, one inch square, resting horizontally on supports four feet six inches apart, shall stand, without breaking, a weight of 550 pounds suspended at the center.* In casting pipe 30 inches and above in diameter the metal shall be poured twice in order to secure a thorough mixture.

2. All straight pipes shall be cast vertically, in dry sand molds and loam cores, with socket-end down.

3. All pipes and special castings shall be cooled gradually to avoid chilling or unequal contraction in any part.

4. All pipes and special castings shall be cast with sockets and spigots, or with flanges, as specified or ordered.

5. All socket-and-spigot pipes and special castings shall be square at the ends and at the inner edge of sockets, and of the exact internal diameter and dimensions specified. Their sections shall be truly circular and concentric, and their thickness uniform throughout their length between socket and spigot. They shall be free from cracks, cinders, scoria, blisters, air and sand holes, cold-shuts, and all other imperfections. They shall have a smooth surface inside and outside. All inside projec-

*The deflection of this bar should also be specified as not less than one inch, in order to obtain a measure of its resilience. See Art. 151. J. B. J.

tions must be carefully removed and made even and smooth throughout. No plugging of holes or flaws will be allowed. All spigot-ends shall fit well into sockets to the bottom, without requiring chipping in the field.

6. The weight of the straight pipes, their joint room, length and thickness shall be as follows:

Interior Diameter, Inches.	Weight in Pounds.	Hyd. Test Pressure in lbs. per sq. in.	Thickness of Joint Room.	Total Length.	Thickness in Inches.
4	298	300	3/8	12' 4"	1/2
6	480	300	3/8	12' 4"	9-16
8	695	300	3/8	12' 4"	5/8
12	1,011	300	3/8	12' 4"	5/8
24	2,753	250	3/8	12' 4"	7/8
30	3,705	250	1/2	12' 4½"	15-16
36	5,018	250	1/2	12' 4½"	1 1-16
48	8,676	200	1/2	12' 5"	1 3/8
60	12,763	200	1/2	12' 5"	1 5/8
72	17,628	200	1/2	12' 5"	1 7/8

7. The joint rooms shall not vary more than one-sixteenth of an inch, and the lengths shall not differ from the above except by written consent of the chief engineer, in which case the weights as above given shall be modified in accordance therewith.

8. No pipe whose thickness of metal is more than one-sixteenth of an inch less than above specified shall be received.

9. Straight pipes weighing less than 97½ per cent of the above specified weights shall be rejected. Any excess of weight of more than 2½ per cent in individual pipes shall not be paid for. Special castings weighing less than 97 per cent of the standard calculated weight shall be rejected. Any excess of weight of special castings of more than 4 per cent shall not be paid for.

10. The sockets and spigots shall conform in shape and size; and the curved pipes, branches, crosses, and other special castings shall be made in conformity with the drawings furnished and approved by the chief engineer.

11. Lugs shall be cast on all such pipes and special castings as may be directed by the chief engineer. The sockets and spigots shall be tested by suitable gauges, and the thickness of the metal shall be tested by calipers.

12. Flanged pipes shall be cast vertically in dry sand molds and loam cores in a manner similar to the socket-and-spigot pipe. All flanges shall be smooth, sound, and free from all imperfections; to accomplish which the upper flange shall be cast with a suitable sinking head thereupon, which shall afterwards be cut off. Before coating the pipes the

flanges shall be faced in the lathe at right angles with the axis of the pipes and drilled by template for bolt connections, as shown on the drawings.

13. Every pipe and special casting shall have cast upon it, in letters and figures two inches long and 1/8 inch in relief:

(1) The maker's name or initial.
(2) The year in which the casting was made.
(3) The running number of each successive casting made of the different kinds and sizes required. The serial number of rejected pipes or specials shall not be duplicated.

14. The pipes and special castings shall be free from rust, and shall be carefully cleaned with both hard and soft brushes, to remove all adhering sand, clay, and dust, or the exterior and interior surface of the pipes and special castings shall be thoroughly cleaned by the use of the sand blast if elected by the trustees. Both the inside and outside surfaces of the pipes must be smooth before and after dipping.

15. After the pipes and special castings have been cleaned to the satisfaction of the chief engineer, they shall be subjected to a careful and thorough hammer inspection, after which they shall be thoroughly dried and uniformly heated in suitable ovens to a temperature of 300 degrees Fahr., and then dipped vertically in a bath of coal-tar varnish composed of 5 per cent of resin and 95 per cent of the best coal tar, distilled at a temperature of 440 degrees Fahr., evaporating all the lighter oils and retaining the heavy oils. Each pipe shall be heated to a temperature of 300 degrees Fahr., and shall at that temperature be dipped into the coal-tar varnish, which shall be maintained at a uniform temperature of 280 degrees Fahr., while the pipe is immersed. The pipe shall remain in the varnish at least ten minutes; then withdrawn, drained, and quickly dipped a second time to insure the coating of all parts which may have remained uncoated. The dipping material must be kept free from sand, grit, or other foreign material. The uniformity of the composition must be maintained by adding fresh materials; and as often as may be necessary, in the opinion of the chief engineer, the tank shall be emptied and refilled with clean and pure material. The coating must be adhesive, continuous, smooth, hard, yet tough, tenacious, and durable. It must be free from blisters and bubbles.

16. After being coated, every pipe and casting shall be drained of the surplus varnish, and when dry shall be tested, at the expense of the contractor, under such hydrostatic pressure as is specified for each size of pipe in paragraph 6 of these specifications.

17. After having been coated and tested, every pipe and special casting shall be carefully weighed under the supervision of the chief engineer, and the weight and class thereof, as well as the inspector's initials, shall be marked thereon in plain, legible letters and figures, in white paint, inside and outside.

18. An inspector appointed by the board of trustees, "commissioners of waterworks," shall, under instructions and direction of the chief engineer, inspect and supervise the work and material, and see that all the stipulations of the specifications are faithfully carried out. He shall have unrestricted access to all parts of the works. All tests and weighing shall be made under his personal supervision, and the contractor shall furnish him with all facilities, and with all tools, specimens, appliances, and labor necessary for this work without charge.

19. A final inspection may be made after the pipes or special castings have been delivered, and any pipe or casting found defective at any time after acceptance by the inspector, and at the time of unloading on the waterworks grounds, shall be rejected, and the contractor shall replace them with good pipes and special castings acceptable to the chief engineer, free of cost to the board of trustees, "commissioners of waterworks."

20. All scales used for weighing and all gauges used in testing shall, whenever required by the inspector, be tested by proper authorities with standard United States weights and gauges.

21. All pipes and castings shall be delivered on board cars on the side track to be built on the waterworks grounds near California, Ohio, and connecting with the Cincinnati, Georgetown & Portsmouth Railroad.

22. All pipes and special castings shall be delivered in all respects sound and comformably with the specifications. In handling or transporting the pipes or special castings, care must be taken not to injure the coating in any manner, nor shall any pipes or other material be placed inside of any pipes or special castings after they have been coated.

23. The prices paid for the pipes and special castings shall include all the materials, patterns, labor, freight charges, the cost of testing, facing, drilling, coating, weighing and marking, and other expenses necessary or incidental to the manufacture and delivery of said pipes and castings on board cars on the waterworks grounds near California, Ohio, excepting the salary of the inspectors appointed by the trustees. The ton shall be the net ton of 2,000 pounds.

24. The prices paid for straight pipe shall include

straight pipes of all lengths not exceeding 12 feet and not less than 6 feet. Straight pipes with socket or spigot at one end and flange at the other end shall be paid for as flanged pipes.

25. Special castings with socket or spigot at one end and with flange at the other end shall be paid for as flanged specials.

G. H. B.

153. Specifications for Riveted Steel Water Pipe.—The following specifications were used for the riveted steel conduit of the city water supply of Cambridge, Massachusetts.* There is no question but that rivet heads and the lapping of the sheets at the transverse joints greatly retard the flow of the water and consume a large portion of the hydraulic head. This might be avoided by counter-sinking the rivets (if the metal be thick enough) and by using an outside butt-strap connection at the transverse joints. The author suggests these changes in the following specification:

Metal.—The steel for the plates used in the manufacture of the pipe to be of class termed soft, and shall be made by the open hearth process. It shall contain not more than 0.06 per cent of phosporus, 0.06 per cent of sulphur, and 0.60 per cent of manganese.

The steel must also stand the following physical tests:

Tensile strength to be not less than 55,000 pounds nor more than 65,000 pounds per square inch.

Elastic limit to be not less than 30,000 pounds per square inch.

Elongation to be not less than 22½ per cent longitudinally and 20 per cent transversely of the plates.

Tensile test specimens to be 8 inches long and 1½ inches wide between measuring points.

Bending test specimens cut lengthwise or crosswise from the sheet to be six (6) inches long and one (1) inch wide, to be bent 180 degrees upon itself when cold, and hammered down flat, without sign of fracture on the outside of the bent portion.

Punching test specimens to be one and three-fourths (1¾) inches wide and not less than ten (10) inches long, in the middle of which a row of not less than eight (8) holes three-

*See a paper by the author of these specifications on The Use of Steel for Water Mains in *Jour. N. E. Water Works Association*, Vol. XIII.

fourths (3/4) inch diameter spaced one and one-fourth (1 1/4) inches between centers shall be punched without causing any cracks.

Drifting test specimens to be three (3) inches wide and not less than five (5) inches long, in which not less than two (2) holes three-fourths (3/4) inch diameter, spaced two (2) inches between center and one and one-half (1 1/2) inches from the edges, shall be punched and then enlarged by blows from a sledge hammer upon a drifting pin until said holes are at least one and one-fourth (1 1/4) inches in diameter, without causing any cracks; such enlargement to be done cold.

The plates shall be free from lamination and surface defects, and be fully up to the required gauge for thickness on the edges. Any plate whose thickness at any point may be found less than ninety-five (95) per cent of the required thickness, shall be rejected without appeal; furthermore, at least ninety (90) per cent of the plates must be of the required thickness at all points.

Rivet steel shall be soft and have a tensile strength between the limits of 50,000 and 58,000 pounds per square inch, with an elastic limit of not less than 30,000 pounds per square inch, and with an elongation of not less than 28 per cent in a test bar eight inches long between measuring points and full diameter of rivet, and with a reduction of cross sectional area at the point of fracture of not less than 50 per cent.

The material shall also be of such quality as will stand bending double and flat before and after heating to a light yellow heat, and quenching in cold water, without sign of fracture on the convex surface of the bend. The quality of material of rivet rods and subsequent manufacture into rivets shall be such that the edges of heads of properly heated and driven rivets shall be free from checks or cracks. All steel rivets not conforming to the above requirements will be rejected.

All plates and rivets must be free from rust and be kept under cover, from the time of manufacture of the plates until the completed pipe is dipped or coated. In case of accidental rusting, the rust must be removed from the plates in the manner hereinafter specified before proceeding with the manufacture of the pipe.

Manufacture of Pipe.—The sheets or plates must be of such dimensions as to admit of being rolled into true cylinders not less than seven (7) feet in length and of the required internal diameters, with ample allowance for the necessary overlap at the single longitudinal seam of each such cylinder. One-half of the whole number of sheets will be formed into "inside courses," or cylinders, having the specified internal

diameter of the conduit pipe, and the remaining half into "outside courses," or cylinders, whose internal diameter shall be exactly equal to the external diameter of the inside courses, said courses alternating and forming a tight fit with each other before any protective coating is applied to the metal.

The conduit pipe shall be forty (40) inches in internal diameter of the said inside courses. The thickness of the steel plates for the pipe with flanged ends to be placed within the reservoir is to be ¼ inch. The thickness of the plates for the pipe at the crossings over the roadway and at the railroad will be ⅜ inches. The thickness of the plates for all the rest of the pipe will be 5-16 inches.

The edges of each plate must be properly planed or cut to true lines and beveled for caulking all around; and at the end of each course, where the lap of the longitudinal seam occurs, the plate must be reduced by cold hammering or planing, or both, to a fine edge, through which one of the rivets of the round seam must be driven to insure tightness. In addition to this rivet, still another rivet must be driven through the three thicknesses of plate at such joints. Each plate must be rolled to a perfect cylinder of the required diameter.

All rivet holes must be spaced with precision, and in punching the same, the punch shall be applied to the side of the plate which is to be placed in contact with another. In punching said holes, the best and sharpest dies and punches are to be used, and all burrs caused by the punch on the lower side of the plate shall be removed by counter-sinking.

All rivet holes are not to exceed the specified size of rivet by more than 1-16 of an inch, and are to be so punched that in assembling the several parts of a member together a rivet 1-16 inch less in diameter than the hole, can be entered hot into any hole without "drifting." Occasional variations must be corrected by reaming.

Whenever possible, rivets must be driven by machines capable of retaining the applied pressure after the upsetting is completed. Rivets when driven must completely fill the hole and have full round heads, concentric to the rivet hole, and thoroughly pinch the connected members together.

All loose or imperfectly driven rivets must be replaced by sound and perfect fitting ones.

At each junction of the straight seam and the round seam where three thicknesses of plate come together, and in all places where castings of any description are to be attached to the pipe, special rivets of extra length must be provided and driven.

The rivets used for attaching castings of any description to the pipes and connecting together plates or courses in the field,

or by hand-work in the shop, shall in all cases be of the best quality of wrought iron, and be driven in the best and most workmanlike manner in every respect. All provisions herein contained, relating to riveting done in the shop, shall also apply, as far as practicable, to rivets driven in the field, or along the line of the conduit.

All circular seams to be single riveted, and the longitudina seams to be double riveted, except where shown otherwise o detail plans.

The pipe is to be manufactured in lengths of four or mor courses each, the outside and inside courses alternating wit each other, so that each length will have an outside course on one end and an inside course on the other end; also in such manner that the longitudinal seams will alternate to the right and left not more than one foot from the centre line of the pipe.

Where angles or curves occur in either the alignment or the grade of the conduit, the plates must be cut and punched to the required lines for forming a small oblique angle at the round seams of as many courses as may be needed to produce the given total deflection or curvature in each locality, and the courses must be put together with the longitudinal seams alternating as aforesaid. In general, the deflection angle formed by two consecutive courses may range from one (1) to five (5) degrees in horizontal or vertical projection, according to the locality; but greater deflection angles may be made if ordered by the engineer.

Where ordered by the engineer the ends of the pipe to be provided with suitable flanged rings or collars of steel or iron, riveted to the pipe and drilled for bolting as shown on detail drawings.

Stiffening rings of suitable steel or iron shall be placed about the pipes and securely riveted to the same where ordered by the engineer. The price for furnishing and placing the flanges and rings to be paid for by the pound at the price stipulated in item (q), Plan B.

Openings for the manholes, branches, blow-offs, air valves, etc., will be cut, and the cast iron fittings riveted on in the shop before the coating is applied.

All riveted seams and joints of every description shall be thoroughly caulked, both on the inside and the outside of the pipe, in the best and most workmanlike manner for first-class boiler work, while for the necessary distance from all laps the seams shall be both chipped and caulked. The caulking of all seams made in the shop must be done before the coating is applied to the pipe, and every precaution must be taken, both in the shop work and in the field work, to insure the utmost strength and tightness.

The cost of furnishing all appliances, materials and labor required for the manufacture of the pipe as aforesaid, except the castings and special fittings, must be included in the price bid per lineal foot for the conduit pipe laid in place complete, said price also to include the cost of riveting such castings and fittings to the pipe, the cost of making connection with the ends of the special sections and ends of the cast iron pipe at the engine house and at the reservoir, and all incidental work.

During its manufacture, sample lengths of pipe, to be selected by the engineer as frequently as he may deem necessary, shall be tested before or after coating under a water pressure equal to at least 100 pounds per square inch. All such tests will be made at the contractor's expense, and he shall furnish all the necessary appliances and labor for their performance to the engineer's satisfaction.

Coating.—After the pipes are manufactured and the openings required for connections, manholes, air valves, etc., cut in the appropriate sections, and the stiffening rings, collars, and fittings, riveted in place, they are to be covered with a protective coating of the material and in the manner recommended by Prof. A. H. Sabin of Long Island City of New York, or by some process equally satisfactory to the engineer.

If the process of Prof. Sabin is used, the pipe will be heated to above 212 deg. Farenheit. It will then be dipped in the coating compound manufactured by E. Smith & Co. of New York, which must be heated to above 250 deg. Farenheit. After draining, the pipe will then be placed and kept vertically in a suitable baking oven with a pan under each pipe to catch the drip.

The pipes must be kept in the oven at a heat of not less than 500 deg. Farenheit, for about four hours, until the coating has become hard; when cold, the pipes may then be removed from the oven and transported to the work.

The heads of all rivets driven after the coating has been applied, or any parts of the coating injured in shipment, must be thoroughly covered with "black bridge paint," manufactured by E. Smith & Co. of New York, and allowed to become sufficiently hard before being handled or covered up.

Manholes.—When directed by the engineer, the contractor shall furnish and put in place in the steel pipe conduit, manholes, with covers, gaskets and bolts complete. The openings for said manholes shall be elliptical, with clear major and minor diameters of not less than 16 and 14 inches respectively; and the joint between the frame and cover must in all cases be made by truly facing or milling the abutting surfaces and interposing a suitable gasket of sheet copper or lead. No portion of the frame or cover shall project within the cylindrical cross-

section of the pipe, and the design of the manhole in all its details shall be subject to the approval of the engineer.

Payments for all manholes ordered and put in place in conformity with the engineer's directions, will be made at the price stipulated in item (p), plan B, but any manhole not so ordered and which is put in place by the contractor at any time for his own convenience during the construction of the conduit or for making any repairs thereto, and the replacement of gaskets in any manhole opened for any purpose by him, will be at the said contractor's expense.

Transportation and Delivery.—After the steel pipe is manufactured and coated as specified above, it is to be transported and delivered along the route of the pipe line, or on adjacent land, as directed by the engineer. Great care must be taken by the contractor in the transportation and delivery to prevent injury to the coating of the pipe and special fittings and castings, or deformation and damage to the pipe itself. All damage to the coating must be made good by the contractor by re-coating the damaged portions in a manner satisfactory to the engineer.

Any section of the pipe showing appreciable indentation or deformation may be rejected by the engineer.

The pipe is to be placed by the contractor in the trenches as prepared by the city, upon wooden blocks set by said city, and the sections of the pipe carefully riveted together. Rivets to be of same quality as those specified for shop riveting, and will be well and thoroughly driven by hand. After riveting, the joints must be thoroughly caulked.

The sections of the pipe shall be so laid as to have the longitudinal seams on top. Rivet heads and all portions of the pipe coating injured in the laying shall be coated while in the trench with the "black bridge paint," manufactured by E. Smith & Co. of New York, in a manner satisfactory to the engineer.

Setting Valves.—The city will furnish and deliver at the work the four sets of 30-in. valves and the cast iron connections; and the contractor is to connect the same with the flanged ends of the pipes, furnishing therefor all bolts, lead, labor, etc. The foundation and rests for the valves and special connecting pipes will be furnished and set by the city.

The sum to be paid for placing each set of 30-in. valves and connecting pipes, also placing the 30-in valve and special castings at the cross-over near the Watertown Branch Railroad, and connecting with the ends of the 40-in. riveted steel pipe is specified in item (n), plan B.

Excavation of the trench, for the pipe-laying and making

up the joints, will be done, also all cradles and bearing blocks will be furnished and set by the city, in advance of the work of placing the pipe. Any damage done to the trench or disarrangement to the blocks and bearing pieces after the same has been dug or set, must be made good by the contractor. The cost of connecting the steel pipe with the cast iron pipe at the engine house and also the gate house of the reservoir must be included in the price for the steel pipe.

The pipes and appurtenances must be kept well brushed out and thoroughly cleansed from all dirt or rubbish of any kind and the ends of the pipe and branches must be kept covered with suitable wooden caps.

Testing Pipe.—As soon as practicable after the pipe is laid and riveted in the trench the pipe will be tested, at the expense of the contractor, in convenient lengths of about 2,500 feet, to a pressure of 100 pounds per square inch. The contractor must furnish at his own expense such caps and plugs as may be necessary to close the open ends of the pipe. During this test all the joints shall be carefully examined and leaky joints caulked and made tight in a manner satisfactory to the engineer. The contractor to supply all needed water and appliances for testing at his own expense.

If, during the test, any pipe, special fitting or casting supplied by the contractor, should burst or be found defective in any respect for any cause, the same shall be removed and be replaced with a sound piece, and any damage to the trench or property resulting from said defect or failure must be made good by the contractor without extra compensation.

At the completion of the work the entire pipe line as laid will be inspected inside, and any material found therein must be removed by the contractor.

It is to be understood that all the necessary materials, tools, machinery, derricks, labor, etc., necessary for manufacture, delivery and placing of the pipes, and setting the gates and special castings, in the trench complete and ready for use, is to be furnished by the contractor.

The price to be paid per each lineal foot of 40-in. riveted steel conduit pipe furnished, manufactured, coated and placed in the trench and accepted by the engineer is specified in item (h), plan B.

Riveted Pipe with Flanged Ends.—The 40-in. riveted steel pipe with flanged ends will be made of sheets ¼ inch in thickness, of dimensions as shown in detail drawings, and made under the foregoing general specifications.

This pipe will not be placed in the reservoir by the con-

tractor, but will be delivered on adjacent grounds as directed by the engineer.

The price to be paid for each lineal foot of 40-in. riveted steel pipe with flanged ends delivered on the ground, is specified in item (i), plan B.

The sum to be paid for each pound of wrought iron or steel collars, stiffening rings, etc., classed as "special fittings," furnished, and riveted to the pipe, as directed, is specified in item (q), plan B. L. M. H.

154. Specification for Wooden Stave Pipe.—The following specification was prepared and used in California by one of the most experienced engineers in this kind of construction:

Dimensions.—The stave pipe built under these specifications shall have inside diameter as near as may be of 24 inches for the reservoir inlet pipe, and 18 inches for the independent connection between the outlet pipes and the Vermont avenue line; and shall consist of wooden staves, steel bolts, malleable cast saddles and metallic tongue.

Staves.—The staves shall be made of clear redwood, free from sap, which shall have been on sticks at least thirty days before being milled. The finished thickness shall not be less in either case than 1⅜ inches. The broad sides shall be dressed to conform to the outside and inside radii of the pipe. The edges shall be dressed to the radial planes, except that a slight bead shall run along on edge of each stave. The ends of the staves shall be accurately squared and shall be slotted for insertion of a No. 14 metallic tongue, so as to secure the same position for all staves. The staves may vary in length from 10 to 24 feet, but not more than 10 per cent shall be less than 12 feet, and not more than 40 per cent shall be less than 14 feet.

Bands.—The bands shall be homogeneous mild steel, having a tensile strength of from 58,000 to 65,000 pounds to

the square inch, and the elastic limit shall not be less than 60 per cent of the tensile strength. The elongation shall not be less than 24 per cent in a test piece 8 inches long, and shall bend back upon itself cold without fracture. The section of the band shall be ⅜ inch round. The thread shall be cold rolled, and shall be as strong as the body of the bolt. The washers shall be 0.11 inches thick, and the nuts shall run easily but not loosely on the thread.

Saddles.—The saddles shall be of best malleable cast iron of such shape as shall leave the entire band in a plane perpendicular to the axis of the pipe. The strength shall be in excess of the bands. They shall be free from defects and shall fit closely upon the outside of the pipe.

Tongues.—The tongues shall be 1½ inches wide, and long enough to extend into the adjacent side staves when in place.

Construction.—The pipe when laid shall conform accurately to the stakes of the engineer. The staves shall break joints, and no joints in adjacent staves shall be nearer than 24 inches. The pipe when finished shall be round and smooth, both outside and in.

The bands shall be put on at right angles to the staves. The seam joints shall be made tight by frequent and thorough cinching of the bands. The butt joints shall be made tight by longitudinal driving of the staves, using wooden driving bars.

Coating.—The steel rods shall be coated with Asphalt after the manner specified for the iron pipe. Any spots where the coating has become damaged, after the bands are placed in the pipe, shall be thoroughly painted over. The nuts, washers and shoes shall be similarly treated.

Spacing.—The band spacing shall be as given in the following table:

(The pressure to be the difference between the elevatioı of the bottom of pipe and 493.5 feet.)

Diameter of Pipe.	Pressure in Feet Head.	Distance C. to (
18 inches	25 to 30	9 inches
18 inches	30 to 35	8 inches
18 inches	35 to 40	7⅞ inches
18 inches	40 to 45	7⅝ inches
24 inches	25 to 30	8 inches
24 inches	30 to 35	7¼ inches

Backfilling.—The contractor supplying the pipe ı also backfill the same to a depth of six inches over the to the pipe; the material to be carefully tamped under and about the same.

Connections.—The pipe shall be connected up with the various specials as shown on the plan with oakum and lead joints. A. L. A.

155. Specifications for Wrought Iron Chains.

The following specifications for wrought iron chains are in use (1902) by the Pennsylvania Railroad Company. It will be noted that there is no specification concerning the material from which the chains are made, the tests of the completed chains being regarded as sufficient. Presumably to satisfy these requirements an excellent quality of wrought iron would be required.

All chain will be ordered subject to inspection and test by the company's inspectors before shipment. Manufacturers filling orders will, when they have a shipment of chain ready, so advise the general superintendent of motive power. They will be required to furnish suitable testing machines, and such assistance as will enable the inspectors to properly determine whether the chain meets the requirements, and must be prepared to ship in the presence of the inspectors.

All chain will be proof tested to the strains shown in the table below, which it must stand without deformation, and in addition one short length of not less than two (2) feet for each

two hundred (200) feet presented, shall be tested to destruction, and the two hundred (200) feet will be rejected if the test length falls below the figures given for breaking weight and elongation. On orders calling for less than two hundred (200) feet, one length will be tested to destruction. When chain is ordered in lengths complete, with links, hooks, etc., welded on, as used on cars or for cranes, the long links, hooks and eye bolts must be included in the proof test, such lengths may be chained together by temporary shackles during the test. One per cent of the chain thus presented for test must be measured and weighed to determine the weight per foot of chain, not including long links and hooks. If it should be impossible to determine weight of chain with long links and hooks attached, the long links must be cut and afterwards replaced in the presence of the inspector before shipment, but with care this cutting may generally be avoided.

All chain must be smooth, free from the appearance of burnt welds, cracks or overlaps, and must have a workmanlike finish. Any chain defective in these respects will be rejected. Chain must not be less than the nominal size in the body or welds. Any chain found defective after shipment, will be returned without freight charges. Chain weighing in excess of the limits of weight shown in the table below, will be paid for at that weight.

The company's drawing of "Standard Chain Links" No. 13124 and detail drawings of "Standard Chains" will form part of these specifications. Drawing No. 13124 gives the desired dimensions of links, and if the length of 100 links in any of the crane chains is greater than shown, by as much as one per cent., the same will be rejected. In the case of the $\frac{5}{32}$ inch and $\frac{3}{16}$ inch chains, as much as ten per cent excess length of link will be allowed. For the remaining chains this limit will be two per cent. To determine the length, a piece of chain containing 100 links whenever practicable will be selected, and the distance from inside end to inside end of end links measured, this measurement will be taken while the chain is in test machine for proof test, with no more than ten (10) per cent of the proof load on to take up the slack. If the

length of chains ordered will not contain 100 links, then 50, 25 or 10 links may be measured. The highest practicable number should however always be selected.

The main requirements of the specifications are given in the following table:

Number on Drawing.	Nominal Diameter of Wire. Inches	Description.	Specifications.				
			Maximum Length of 100 Links. Inches.	Weight Per Foot. Pounds.	Proof Test. Pounds.	Breaking Weight. Pounds.	Elongation. Per Cent.
1	5–32	Twisted Chain.	103.1	0.20	....	... ...	...
2	3–16	Twisted Chain.	96.2	0.35	....	.. ...	....
2½	3–16	Perfection Twisted Chain.	151.25	0.266	... . ..	....	...
3	¼	Straight Link Chain.	102.0	0.70	1,500	3,000	10
4	5–16	Straight Link Chain.	114.7	1.10	3,000	5,500	10
5	⅜	Straight Link Chain.	114.7	1.50	3,500	7,000	10
6	⅜	Crane Chain.	113.6	1.50	4,000	7,500	10
7	7–16	Straight Link Chain.	127.5	1.90	5,000	9,500	10
8	7–16	Crane Chain.	126.3	1.90	5,500	10,000	10
9	½	Straight Link Chain.	153.0	2.50	7,000	12,500	10
10	½	Crane Chain.	138.9	2.50	7,500	13,000	10
11	⅝	Straight Link Chain.	178.5	4.00	11,000	20,000	10
12	⅝	Crane Chain.	176.7	4.00	11,000	20,000	10
13	¾	Straight Link Chain.	204.0	5.50	16,000	29,000	10
14	¾	Crane Chain.	202.0	5.50	16,000	29,000	10
15	⅞	Crane Chain.	252.5	7.40	22,000	40,000	10
16	1	Crane Chain.	277.7	9.50	30,000	55,000	10
17	1⅛	Crane Chain.	303.0	12.00	40,000	66,000	10
18	1¼	Crane Chain.	353.5	15.00	50,000	82,000	10
19	1½	Crane Chain.	416.6	21.00	70,000	116,000	10

P. R. R.

157. Specification for the Material and Workmanship of a Steel Stand-Pipe.

—The following specification for the material and workmanship suitable for a steel water tower or stand-pipe have been prepared by Mr. Wm. D. Pence, after a very long and careful investigation of the numerous failures which have occurred in such structures and also of the materials and workmanship suitable and necessary

for this kind of work. The specification includes a phosphorus limit of 0.06 of one per cent., whereas those given in articles 154 and 156 allowed an upper limit of 0.08 of one per cent. There is no question but that a limit of from 0.06 to 0.08 of one per cent., is necessary in order to exclude high phosphorus steels which are of necessity brittle. The author heartily commends these specifications, not only for the purpose named, but for all similar kinds of work.

Material. The metal composing the stand-pipe shall be soft, open-hearth steel, containing not more than 0.06 per cent. phosphorus, and having an ultimate tensile strength of not less than 54,000 nor more than 62,000 pounds per square inch, an elastic limit not less than one half the ultimate strength, an elongation of not less than 26 per cent. in eight inches and a reduction of area of not less than 50 per cent. at fracture, which shall be silky in character. Before or after being heated to a cherry red and quenched in water at 80° F., the steel shall admit of bending while cold, flat upon itself, without sign of fracture on the outside of the bent portion.

Test Pieces. All test samples shall be cut from finished material. Tensile test pieces to be at least 16 inches long, and to have for a length of 8 inches a uniform planed-edged sectional area of at least ½ square inch, the width in no case to be less than the thickness of the piece. Bending test pieces to be 12 inches long, and to have a width of not less than four times the thickness, with edges filed smooth.

Number of Tests. For the purpose of identification the number of the melt or heat of steel shall be stamped on each plate produced therefrom. At least one full series of tests, both chemical and physical, as above specified, shall be made of each melt, and such additional tests may be made as, in the judgment of the inspector, seem essential for corroborative purposes under varying conditions or methods of treatment of the metal.

Finish of Material. All plates must be free from laminations and surface defects, and shall be rolled truly to the specified thicknesses.

Facilities for Testing. Complete facilities for the tests and inspections shall be provided by the contractor, as required.

Inspector. Material will be inspected at the mill by (name of a trustworthy testing concern equipped to make both chemical and physical tests) or such other party as may be approved by the engineer.

Additional Test Pieces. If required by the engineer, the contractor will provide four certified samples of each thickness

of plate used in the work, these samples to be 2 inches wide and 16 inches long.

Workmanship. All workmanship must be first-class in every particular.

Working Steel. The plates and angles shall be shaped to the proper curvature by cold rolling. No heating and hammering shall be allowed for straightening or curving, or for other purposes.*

Punching. The work shall be carefully and accurately laid out in the shop, and the rivet holes punched with a center punch, sharp and in perfect order, from the surface to be in contact. The diameter of the punch shall not exceed that of the rivet by more than 1-16 inch, and the diameter of the die shall in no case exceed that of the punch by more than 1-16 inch. Rivet holes in plates having a thickness of ¾ inch, and over shall either be drilled or if punched, shall be reamed not less than ⅛ inch larger than the die sides of the holes, and sharp edges shall be trimmed.

Beveling, etc. All calking edges shall be planed to a proper bevel. All parts must be adjusted to a perfect fit, and properly marked before leaving the shop.

Erection. In assembling the work, the rivet holes shall match so that hot rivets may be inserted without the use of a hammer. Drifting is prohibited. Eccentric holes, if any, must be reamed, and if required, larger-sized rivets shall be used in such holes.

Rivets and Riveting. The best grade of soft charcoal iron rivets to be had in the market shall be used. Sufficient stock must be provided in the rivets to completely fill the holes and make a full head. The rivets shall be driven at such a heat as will admit of their being finished in good form with a button set before the rivet has cooled to a critical point. As often as may be deemed advisable for the purpose of testing the work, rivets shall be cut out at the direction of the inspector. The quality of the rivet metal and of the workmanship shall be such that the fracture of the rivet so removed at random shall show a good, tough, fibrous structure without any crystalline appearance, and there shall be no evidence of brittleness. Loose rivets must be promptly replaced, no rivet calking being permitted.

Calking. All seams must be calked thoroughly tight with a round-nosed calking tool by workmen of acceptable skill. Great care must be taken not to injure the under plate.

Rejections. Defective material and workmanship may be rejected at any stage of the work, and must be properly replaced by the contractor as directed.

*If lap riveting is used, omit the expression "or for other purposes," and insert the following sentence: "No scarfing shall be done at a temperature below that of ignition of a hard-wood hammer handle, and no work shall be done upon the steel between

Final Tests. After completion the work shall be tested by filling the stand-pipe with water, and the leaks, if any, shall be promptly and thoroughly calked. The stand-pipe must be water-tight before acceptance.

Superintendence. All inspections shall be made under the direction of the engineer who shall have general supervision of the work.

W. D. P.

MISCELLANEOUS SPECIFICATIONS.

158. Specifications for Pile and Trestle Bridging.

The following specifications for pile foundations and timber trestles are those used by the Union Pacific Railway Co. These specifications may, however, serve as a standard for all kinds of pile foundations, and for the selection of large timbers for engineering structures. The formula for obtaining the safe bearing resistance of pile foundations is that generally known as the "Engineering News formula."

All piles to be made from straight, sound, live timber, free from cracks, shakes and rotten knots, cut from the following kinds of timber: White Oak, Burr Oak, Red or Yellow Oregon Fir. They must be so straight that a straight line taken in any direction from the center of each end of the pile, and run the length of it, shall show that the pile is at no point over one-eighth of its diameter at such point out of a straight line. They must show an even, gradual taper from end to end. Ends must be cut square, all bark taken off, branches and knots trimmed off smooth, finishing the pile in a workman-like manner. They must not be less than fourteen (14) inches in diameter at the narrowest point of measurement of butt or large end, nor less than ten (10) inches in diameter at narrowest point of measurement of point or small end, and at no part more than seventeen (17) inches in diameter.

All piles must be properly sharpened before driving. They must be driven until they will carry a safe working load of—— pounds, computed by the following formula:

$$L = \frac{2wh}{s+1}$$

In which L = Safe load in pounds.
w = Weight of hammer in pounds.
h = Fall of hammer in feet.
s = Last penetration in inches

They will be estimated and paid for by the lineal foot. 1. As delivered at the site of the structure, according to bills furnished by the engineer. 2. For driving, straightening and cutting off ready for the caps, and only the length actually left standing in the structure to be paid for.

All timbers must be of the exact dimensions given and figured on the plans, to be cut from sound, live timber, free from loose or rotten knots, worm holes, wind shakes or splits; reasonably well seasoned, straight grained, square edged, and free from any and every defect calculated to impair its strength and durability. It will be estimated and paid for in the work by the thousand feet, board measure. The following kinds of timber will be accepted:

All bridge ties will be White or Burr Oak, Oregon Red or Yellow Fir, Tamarack, or Yellow Pine.

All track stringers and guard timbers will be Oregon Fir or Yellow Pine, of the long leaved, southern hard pine variety.

All posts, caps, sills, bracing and end plank will be White or Burr Oak, Red or Yellow Oregon Fir, White or Yellow Pine, or Tamarack.

All wrought iron must be of the best quality of refined iron, tough, ductile, and capable of standing a tensile strain of fifty thousand (50,000) pounds per square inch of sectional area. The manufacture of the bolts must be perfect in every respect, and have nuts and screws of the United States standard dimensions, length of thread to be not less than three inches.

All washers and spacing blocks, etc., must be well manufactured of good gray iron and to the exact dimensions shown on the drawing. The cost of placing all bolts, spikes, and washers in the structure will be included in the price paid for framing and erecting the timber.

All bridge ties will be furnished and placed in the bridges by the contractor.

The surface of the ties must be brought to a true plane under the rail, so that the rail will get a full bearing on every tie.

All of the track stringers shall be brought to a true plane, so that ties will get an even bearing on all the stringers.

Where any timber or pile trestle bridge is built on a curve, the blocking for elevating the outer rail, or other means for elevating it, will be as per drawings for the same, a copy of which will be furnished from the office of the chief engineer.

The culverts will be put in place and finished ahead of the grading, so that it will not interfere with or detain the grading, in any way.

Bridging shall begin when directed by the engineer, and progress at a rate sufficiently rapid to keep out of the way of the tracklayers.

When directed by the engineer drain pipes will be used instead of culverts; they will be of cast iron or vitrified terra cotta; this will be carefully bedded and jointed and of such size as may be directed by the engineer.

All framing shall be accurately fitted; no blocking or shimming will be allowed in making joints; the holes for the bolts shall be bored with an auger of the exact size of the bolts. The nuts on all bolts shall be screwed so the washers shall pinch hard upon the wood and bring all the parts of the structure close together.

On completion pick up and remove all rubbish from the premises.

All material will be inspected on the above specifications, at points of shipment or destination as agreed, and the owners required to remove all rejected material from the company's premises within thirty (30) days from the date of notice to do so. The company after that time will not be responsible for the return or safe keeping of the same.

When from any cause bridge materials are unloaded from cars at material yards or end of track, it shall be reloaded by the contractor at his own expense. U. P. R'y.

159. Specifications for the Steam Plant of a Small Electric Light Station. The following specification for the steam plant of a small electric light station includes specifications for the engine and its attachments, feed water heater, boiler feed-pumps, boilers, furnace, stack and pipe connections. While not especially elaborate, they have been prepared by a mechanical engineer of large experience in this field of practice. They are given here, however, not for the purpose of being copied, but simply as an illustration of such a specification. The reader will note that three kinds of engines have been provided for, and that large liberty is retained by the engineer in the selection of the engine from those submitted for competition in the bids. A particular feed water heater was here specified, because it was thought to be best suited for the kind of water which was to be used, the advantage of this

heater being that it largely removes the scale from hard wate before it enters the boiler:

ENGINE.

Type: There will be one engine, of the High Speed Auto matic pattern; cylinders 10½ inches or 11 inches diameter capable of operating continuously at 600 feet piston speed pe minute, without undue heating.

Regulation: The automatic governor must permit a cut off as late as ½; and must be so adjusted, that the difference i speed, when running with 100 pounds initial pressure and n load, as compared with 75 pounds initial pressure and cut-off ½ shall not exceed a guaranteed amount to be stated by bidder with a correspondingly less variation inside of the limits named The regulator must be so constructed, as to permit this guar anteed regulation to be easily maintained, without racing.

Fixtures and Fittings: Standard cast iron sub-base, an two heavy driving pulleys, of such diameter and face as may b required to suit dynamo pulleys; a full set of foundation bolts nuts, and plates; template for foundation; throttle and drai valves; cylinder lubricators, automatic oil cups, wrenches, indi cator motion, etc.; and two one-inch relief valves set at 11 pounds pressure.

Dimensions: State diameter and material of shaft an crank pin, and submit drawing or blue print indicating clearl size of cylinders, speed, diameter of pipe openings, space occu pied, and dimensions of foundations.

Corliss Engine: Bids will also be considered under th same conditions on a Corliss engine; 11 inches diameter o cylinder, shaft 6 inches; flywheel and frame extra heavy; spee 100. Regulation to be guaranteed.

Direct Connected Engines: This type will also be con sidered, together with suitable dynamo. High speed. Vertica or horizontal. Compound or single expansion. Full detail must accompany proposals.

Belting: Double thickness, even and pliable, equivalen in strength and adhesiveness to the Shultz Leather Belting. O selected stock, stretched twice before being made into belts No shoulders or flank leather to be used. Its tensile strengt must not be less than 3200 lbs. per square inch of section, an must not be worked beyond 65 lbs. per inch of width. Th belt will be thoroughly stretched again after making, and befor shipment.

FEED WATER HEATER.

One No. 5 Hoppes exhaust steam feed water heater an purifier capable of heating 3,000 pounds of water per hour t the highest point attainable, without back pressure on th

engine. To have steel shell, oil extractor and trap; crane for removing head; automatic water regulator and openings for water and steam as required.

BOILER FEED PUMPS.

One Worthington Duplex pump, 5¼x3½x5, water ends to have packed pist ons. Piston rods, water cylinder linings and water pistons to be of gun metal. Valves suitable for hot water; complete with a full set of oil cups and wrenches.

BOILERS.

To be two in number as follows:

Dimensions: Fifty-four inches diameter, eighteen feet long; thickness of shells, five sixteenths; heads, seven sixteenths, to have half smoke-box extension, bolted on, sixteen inches in length.

Material: Park Bros.' Open Hearth Homogenous flange steel of 60,000 pounds tensile strength. All plates to be stamped with name of maker, quality and tensile strength.

Construction: The heads are to be machine flanged, to have an easy radius; and amply braced, with braces of best refined iron, uniformly distributed, so that each brace will carry its full share of strain. Before beginning construction a plan of the bracing proposed must be submitted to the engineer for approval.

Tubes: Thirty-eight—4 inches in diameter, 18 feet long, of lap welded, charcoal iron; carefully and properly expanded and beaded over.

Dome: Thirty inches diameter, thirty inches high. To be of same material as shell; well braced and double riveted.

Seams: There will be one longitudinal, double riveted seam, in each sheet, well removed from the fire. Other riveting single. The make, size and spacing of rivets shall be in accordance with the best modern engineering practice.

Supports: There will be two extra heavy cast iron lugs for each side; each 4½ feet from end of the boiler. The forward lugs to rest directly on cast iron plates 12 inches square, supported by the masonry. The rear lugs will rest upon 9 one-inch rollers, which in turn will rest upon 12x12 plates.

Stack: Of sheet steel, No. 12 gauge in thickness, diameter 32 inches, height 50 feet. Lower end Y shaped to fit stack plates. Furnish sufficient ⅜ inch galvanized iron guy wire to make two complete sets of guys. Support stack underneath Y to brick work or floor.

Fittings: One 5-inch chime whistle; one soot sucker, complete, with hose and handle; one flue scraper; one steel barrow; complete set of firing tools, consisting of shovel hoe, slice-bar, and poker; 2 eight-inch steam gauges; 2 one and one-

quarter inch combination water columns, with gauge cocks, and water glasses; two 4-inch safety valves, with levers marked to 150 pounds pressure; 2-inch check, stop and blow-off valves.

Castings: Two square top, full flush fronts of approved ornamental design, with tight fitting doors, and anchor rods extending the entire length of brick work; six 9-foot binding bars with cross and archor rods; soot door and frame; stack plate and damper. Cast iron skeleton frames suitable for standard sizes of fire brick, to be used in place of back plates. Rocking grates will be furnished and erected by the city.

Openings. The man hole in front head under tubes, and one in shell back of dome, both properly reinforced, and provided with heads, arches and bolts complete; two 1¼ inch openings for water column; one 2-inch for feed and blow off pipe; one 4-inch main steam outlet, and one 4-inch for safety valve; all to be properly reinforced and located as directed by the engineer.

Inspection and Insurance. Before shipment the boilers will be tested and made tight under a water pressure of 150 pounds. Certificate of inspection and insurance policy in the Hartford Steam Boiler Inspection and Insurance Company, for the sum of $500, for one year must be furnished, for each boiler.

FOUNDATIONS AND BRICK WORK.

(See Drawing.)

The dimensions of foundations for engine, boilers, heaters, pumps, and brick work for furnaces, will be clearly shown in drawings, which must be accurately followed.

Foundations: All are to be of concrete composed of one part best domestic cement, three parts of clean, sharp sand, and five parts clean, broken stone of sizes that will pass through a 2½ inch ring; all to be thoroughly mixed, laid quickly, and rammed down solid.

Excavations: As per drawing. Remove promptly all earth and other debris. Bottom to be level, and rammed if necessary.

Iron Work: All bolts and plates for engines and dynamos must be put thoroughly and permanently into position by the contractor. Outside of each bolt place a piece of 2-inch iron pipe, so as to permit some adjustment of the bolts.

Cap Stones: Foundations for heater, and boiler feed pumps will project somewhat above floor line. Each of these will be surmounted by a neatly cut cap stone, 8 inches thick and of proper dimensions.

Boiler Furnaces: To be of well burned red brick, thoroughly wetted before laying; all joints flushed solid; all courses

level and straight. Every sixth course both inside and outside to be a header. Brick to be laid in mortar composed of one part lime to five parts of sharp sand. Build into side and rear walls a 1-inch air space, which shall be air tight; except immediately under the supporting lugs of boilers, where the walls shall be carried up solid.

Fire Brick Lining: The entire inside of the furnace where exposed to flame, will be lined with A No. 1 hard burned fire brick, laid in dry milled fire clay, with very thin joints, flushed full; headers every sixth course. Use the following special fire brick "Angle B," to form the top and front corner of same, use the "4½ to give the batter on front of bridge wall: at top and bottom, Jamb," also for the inner corners of cleaning out doors openings. Front of bridge all headers.

Closing In Tile: For the sides of furnace, use fire brick tile 6x12x2¼; and for the rear above tubes lay ordinary fire brick special skeleton arch frame.

Iron Work: Place in position all cleaning out doors, cast iron plates and anchor rods.

PIPE CONNECTIONS.

To be as per drawing, which will be furnished.

Steam: Four inches from boiler to 6-inch header leading to engine room, where it will reduce to size required by engine, thence to engine proper size, through a Hine separator suitably drained. Leave Tee having plugged outlets for additional engine and water works pump.

Exhaust: Four inches from engine to main line; thence 6 inches through heater to 5 feet above roof. Leave plugged inlet Tee for additional engine and pump.

Drains: Both the steam and exhaust pipes are to have suitable drains of ample size wherever there is any possibility of water accumulating. Run these drains outside of building.

Small Piping: Feed, blow-off and steam and exhaust pipes for boiler feed pumps to be as per details shown in drawing.

Fittings: Of the best construction, with threads true and clean. Use in all cases what is known as "water" or "sweep" ells and fittings, having extra long radii for curves.

Valves: Of the Jenkin Brothers, or asbestos disk pattern. Use gate and angle valves in preference to globe. When globe valves are used they must be so placed as not to form water pockets.

Supports: All pipe work to be well supported in such a way as to bring no unusual strain on the pipe or fittings; either from their weight, or from expansion or contraction.

Covering: All live steam pipes, domes and top of boilers to be covered with a high grade non-conducting material, such as magnesia ectional.

In General: The arrangement of the pipe work must be such as to provide for all differential strains arising from expansion and contraction. The work to be of the best and most thorough possible. The steam pipe will be tested to 150 pounds. W. H. B.

160. Specifications for Leather Driving Belts.

The following specifications for large leather belts were prepared for the large water power electric plant at Austin, Texas, in 1894. It is thought they conform to the latest and best practice in the manufacture of leather belting.

There are to be six main driving belts and seven belts to drive dynamos, of dimensions as hereinafter scheduled.

These belts are to be of leather made from the best selected, large steer hides, of pure oak-bark tannage. The cuts are to be taken from the centre solid portions of the hides, and are not to include shoulders, flank or soft parts of the hides. Each piece is to be of fine, close fibres and all pieces are to be scarfed to a uniform thickness. No piece taken from one hide is to exceed a net length of fifty inches.

The individual pieces of the leather are to be thoroughly stretched after currying and again machine tested and the utmost stretch, within elastic limits, given to the belts when they have been made up complete.

The transverse lap joints are not to exceed four inches in longitudinal length, are to be scarfed in the best manner, thoroughly cemented and are to be made fast and durable without the use of pegs or rivets. All belt edges are to be properly rounded.

All belts are to be thoroughly water-proofed.

The complete belts are to be soft, pliable, and finished with smooth polished surfaces.

The belts of thirty-eight inch width are to be of double thickness. The outer face pieces are each to be in a single width, with centre conforming to the back-bone centre of the hide. The inner, or running face pieces of the thirty-eight inch belts are to be n neteen inches in net width and to have one and one-half inch scarfed and lapped longitudinal joints. One edge of each half-width will be cut along the back-bone centre of the hide and in the makeup of the belt, these inside half widths are to be placed with the back-bone edges at the outer edges of the belt. These seam sides of the thirty-eight inch belts are to be run next the pulleys.

All the remaining belts are to be of double thickness in single width pieces, with centres of each piece conforming to the back-bone centres of the hide. The belts are to be finished

with uniform thicknesses respectively not less than as follows for each stated width:

38	inches	width	of	not	less than	$\frac{28}{64}$	inches	thickness.
25	"	"	"	"	"	$\frac{24}{64}$	"	"
24	"	"	"	"	"	$\frac{26}{64}$	"	"
14	"	"	"	"	"	$\frac{24}{64}$	"	"
13	"	"	"	"	"	$\frac{24}{64}$	"	"
11	"	"	"	"	"	$\frac{22}{64}$	"	"

The speeds of the belts will be at rates of about 5,000 lineal feet per minute.

All these belts are to be transported to the power house now being constructed by the Board of Public Works of Austin, Texas, in Austin, and are to be placed upon the pulleys in the power house and spliced and cemented in place.

The hides and manufacture, finish and fitting of the belts are to be first-class in every respect and the belts are to be guaranteed to run smoothly and straight upon the pulleys and to work successfully for the space of one year from the time of the starting up of the power house for regular work.

If any defect tending to impair the usefulness or life of any belt supplied under this specification, shall develop within one year that belt shall at once be made good by the manufacturer or replaced by a belt conforming with this specification.

Proposals for these belts, as fitted in place ready for the starting of the machines, are to be delivered to the Hon. John McDonald, Mayor, and President of the Board of Public Works, Austin, Texas, on or before the 8th day of December, 1894, and all belts are to be delivered and fitted in place ready for use within six weeks of the date of the order for their manufacture and delivery.

The Board of Public Works reserves the right to reject any and all proposals as may be for the best interest of the City of Austin.

Blue-prints showing relative positions of the pulleys and inclinations of the belts are submitted herewith.

SCHEDULE OF BELTS.

	H. P.	Width of Belt. In.	Thickness in 64ths of an inch. 64ths.	Diameter of Driving Pulley. In.	Diameter of Driven Pulley. In.	Distance between Centres of Shafts. Feet.	Total Net Length Belt in Place. Feet.
Main Driving Belt	520	38	28	54	54	43.108	100.333
" " "	520	38	28	54	54	42.763	99.663
" " "	201	25	24	54	26	44.970	100.412
" " "	201	25	24	54	26	48.075	106.622
" " "	201	25	24	54	26	45.379	101.230
" " "	201	25	24	54	26	48.687	107 846
Dynamo Belt	241	24	26	56	32	17.851	47.352
" "	134	14	24	50	28.5	18.625	47.222
" "	134	14	24	50	26.5	17.688	45.348
" "	100	13	24	55	18	15.293	39.708
" "	100	13	24	55	18	15.293	39.708
" "	80	11	21	46	18	15.211	38.800
" "	80	11	22	46	18	19.912	48.102

J. T. F.

161. Specifications for Pumps to be Operated by Water Power. The following specification was prepared for the city of Austin, Texas, in 1892, for the construction of two pumps for a city water supply to be driven by water power machinery.

PUMPS.—There are to be two pairs of horizontal, double-acting, plunger pumps, having two pump cylinders to each pair. Each pair of pumps is to have capacity to deliver four million gallons of water per 24 hours.

The dimensions of plunger will be approximately as follows: 1½ foot diameter, 2¾ foot stroke, with 25 revolutions per minute; the plunger speed not to exceed a mean rate of 137½ feet per minute when pumping water at the rate of four million gallons per twenty-four hours.

These pumps are to be adapted for pumping to a reservoir and also for pumping directly into the city distribution pipes with direct pressure, the pump house being located between the reservoir and the city. The static head of the reservoir is 245 feet and the dynamic head approximately 265 feet and the force main to the reservoir is 7,600 feet in length, of 24 inch pipe.

These pumps are to receive motion from vertical turbine shafts having beveled gears which drive a jack shaft. On the jack shaft is to be a spur pinion, which will drive a spur mortise gear on the main pump shaft. On each end of the main shafts are to be balanced crank disks, which will drive the pumps.

The receiving and delivery chambers are to be ample in dimensions, and are to have nests of valves of the best bronze composition of approximately 3 inches diameter, and sufficient in number so that the valves shall not lift more than 3/8 inches each when the rate of delivery of the pumps is at four million gallons per day. The pump chambers will be well provided with hand-holes that will give easy access to each of the valves.

The water supply for each pair of pumps is to be taken from a 30 inch branch in the horizontal penstock in the basement beneath the pump room floor. The necessary admission and discharge pipes, of ample size and easy curves, and a tall air vessel for each pair of pumps are to be provided. The force mains will be connected with the force mains leading to the reservoir, on the outside of the pump house wall, and not exceeding 10 feet distance from the face of the wall.

The pump cylinders will be connected with the main and jack shaft pillow blocks by continuous, heavy cast-iron girders, adapted to carry the bearings and the strains of the connecting rods without tremble or elasticity.

The main and jack shafts are to be of the best wrought iron forgings turned to the diameters indicated upon the drawings, and bossed up to receive the gears. The large gears, of both the spur and bevel pairs, will be mortise gears with their mortises planed, and having thoroughly seasoned, machine cut, smooth maple cogs, fitted and keyed in the most rigid manner. The cogs are to be thoroughly boiled in oil.

Each spur pinion is to be machine moulded, with teeth planed on both sides to match and run with mortise gears. Both gears and pinions are to be bored to fit their respective shafts and to be keyed in place. The pinions are to be feather keyed on the jack shaft and fitted with approved screw motion to move them out or into gear and to hold them where placed.

The jack shafts are to be not less than 6½ inches, and the main shafts not less than nine inches diameter in the bearings.

The two jack shafts are to have their axes precisely in line and are to have a connecting shaft fitted with couplings, bearings and distance plates as directed.

All bearings are to be babbeted and bored out, of ample lenght to insure moderate wear and easy lubrication, and are to be fitted with oil cups.

The cranks will be in balanced disk forms and fitted with mild steel pins. The connecting rods will be of the best wrought iron, and fitted with brasses, steel straps and adjusting keys and babbeted friction bearings. The cross heads will be of forged iron approved model with steel wrist pins. The guides will be rigidly bolted to the girders and adjustable to wear. The plunger rod and plunger stuffing box glands, the valves and all interior bolts and nuts will be of the best solid

standard bronze metal. The plunger stuffing box will be packed with the best quality of "Seldon" or other approved packing. The crank disks, connecting rods, straps and cross-heads are to have polished surfaces.

All bearings and wrist pin brasses are to be fitted with the best oil cups and with proper drip pockets, and drip pipes are to be provided where required.

There is to be furnished and connected with each pair of pumps one 8 inch water pressure gauge, indicating the column of water in both feet head and pounds pressure. There will be a good approved revolution counter fitted to each pair of pumps as directed by the engineer. There will be a long Scotch tube water glass with proper cocks on each air vessel.

The general plan of the power house shows the position of these pumps, the method of connecting their power, and the positions of their suction and delivery pipes.

Full detail drawings of the pumps and their appendages are to be delivered to the consulting engineer and are to be subject, in all respects to his approval. J. T. F.

162. Specification for a Pump Well. The following specification describes a good method of sinking a well from 20 to 50 feet in diameter and to a depth not usually exceeding 50 to 60 feet. Such wells are usually sunk through water-bearing strata, where an open cut would have to be supported by some kind of curbing and this curbing may as well be the masonry well curb itself. In this case it is necessary to rest this masonry upon a shoe which may be made either of wood or iron. In the former case an iron cutting edge should be provided. It is also best to reduce the external diameter of the masonry curb a short distance above the shoe in order to prevent the whole mass from sticking in the process of sinking by its becoming tightly bound by the surrounding earth. It is necessary to anchor the lower portion of the masonry curb to the shoe by means of iron bolts, as indicated in these specifications.

Pump Well.—The pump well shall be constructed within lines to be given by the Engineer, and will consist of a brick curb, laid in cement mortar, on an oak shoe provided with an angle iron ring bolted to the under side of shoe flush with its outer periphery.

Shoe.—The shoe shall be in three rings of unseasoned oak, three inches thick, made up in segments, the segments to be a

true arc upon the outer periphery and bolted together with seven eigths (⅞) inch bolts and wrought iron washers to break joint as shown in drawing marked "Section and Details Pump Well," on file in the office of the Water Works Committee. The width of the shoe shall be twenty-two (22) inches, and when bolted up shall measure nine (9) inches in depth or thickness. The ring shall be of 4x4 inch angle iron five eighths (⅝) inch thick weighing 16.2 pounds per foot, twenty-one (21) feet external diameter, with two fishplates eighteen (18) inches long at each joint, riveted on hot, with four (4) three quarter (¾) rivets staggered, each side of joint; the heads of rivets to be countersunk and finished flush on outside of angle iron ring and shall be attached to the oak shoe with sixty (60) seven eighths (⅞) bolts, placed about one (1) foot and one (1) inch, center to center, on a circle twenty (20) feet, seven and one half (7½) inches diameter. These bolts shall have forged square heads and nuts and wrought iron washers. The oak shoe shall have a diameter of twenty-one (21) feet.

Curb.—The curb shall be of select hard burned front or paving brick, straight, sound and solid, when broken. No over burned or salmon brick will be accepted, and the brick shall be laid on the oak shoe in courses; in full beds of cement mortar, consisting of one part Louisville [fresh burned] cement to 2 parts of clean sharp sand which shall be mixed only as fast as used by the masons. No cement mortar which has had an over dose of water or sand, or which has begun to set in the mortar box shall be used, but all such must be thrown aside. The bricks shall be free from dust and wet with a sprinkling hose or can, or be dipped by the mason in clean water before being placed in the curb and all joints shall be slushed with mortar pressed in with the trowel, as rapidly as the courses of brick work are laid up. NO GROUTING WILL BE ALLOWED.*

The outer and inner faces of the curb shall be laid in true circles of the dimensions shown by the drawing above mentioned, and shall have at the bottom (or on the shoe) an external diameter of twenty (20) feet ten (10) inches, and an internal diameter of seventeen (17) feet four (4) inches, these dimensions for a height of two (2) feet six (6) inches, when the internal diameter shall be contracted by a gradual racking inward of the courses to a height of four (4) feet above the shoe, where the internal diameter shall be sixteen (16) feet eight (8) inches.

From a depth or height of four (4) feet above the shoe to the top of well the internal diameter shall be eighteen (18) feet, and the external diameter shall be twenty (20) feet ten (10) inches from the shoe to the top of well, the thickness of wall at the bottom or on the shoe, and for two and one half

* The author would prefer the grouting to the slushing with mortar, as better calculated to obtain perfectly solid joints.

(2½) feet above, shall be twenty-one (21) inches, four (4) feet above the shoe the thickness shall be twenty-five (25) inches, and for the remainder of heighth or depth, the thickness shall be seventeen (17) inches.

The bricks shall be laid stretchers and headers or with hoop iron bond, as may be directed by the engineer. The contractor to state in his proposal the difference in price (if any), should all bricks be laid as stretchers and the curb bonded from inside to outside with hoop iron.

Should hoop iron bond be used this will be of charcoal iron, No. 16, B. G., one and one half (1 1-2) inches wide cut four (4) inches longer than thickness of wall, with each end turned at right angles for a length of two (2) inches, and shall be placed eighteen (18) inches apart around the wall, and shall occur at every fifth horrizontal joint.

The curb of the well shall be truly cylindrical for all depths, and shall be carried down plumb. The outer surface of the brick work must be true to the arcs and smooth, to prevent sticking as the material is undermined from the shoe, and the inside joints shall be neatly struck as the courses of brick are laid.

Anchor Bolts. The lower or first eight (8) feet of the curb shall be attached to the shoe by ten (10) anchor bolts, eight (8) feet long, of seven eighths (7-8) inch round iron, with square nuts and wrought iron washers at the bottom and square nuts and plate iron washers of one quarter (1-4) inch boiler iron eight (8) inches square at the top, the bolts shall be placed about six (6) feet apart, and built in as shown by the drawing herein mentioned, and after the course of brick next under the washers (at top) has been laid, the nuts shall be all screwed down on the washers, and the excess of thread on the bolts carefully cut off with a hack saw, to avoid disturbance of the brick work just set.

Coping. The well shall be finished with a coping of sand stone ten (10) inches thick, twenty-one (21) inches wide, with an internal diameter of seventeen (17) feet eight (8) inches, to project two (2) inches inside and outside brick work at top of curb. The inner and outer edges of coping on top shall have a chiseled wash one and one half (1½) inches "in" on the bed and one (1) inch "down" on the face. The coping shall be made up in ten (10) segments of uniform length of arc, and shall be dressed to lay with less than one quarter (¼) inch joint. The joints shall be filled with mortar worked in with the trowel and the several segments shall be cramped together with iron cramps of best "½x2½ f. b. iron with legs 2¾ inches long, and width of cramps between legs fifteen (15) inches. These cramps shall be "let" into the beds of stones at the mid-width, flush with the surface of coping, and the leg pockets

shall be cut slightly dovetail with a flare downwards, and after the cramps are set shall be run with hot lead caulked in place. The lower bed shall be chisel dressed to make a joint on a full bed of mortar with the last course of brick, and the faces and upper beds shall be finely chiseled to a smooth even surface.

Excavation. The well will be constructed by the undermining method, a circular hole, twenty-one (21) feet diameter will be sunk in the clay eight (8) or ten (10) or more feet, depending upon the capacity of the material to stand vertical, and at the option of the contractor and upon approval of the engineer. The shoe will then be placed in the hole and carefully leveled, the anchor bolts being in place, the brick curb will be laid as herein provided until the brick work reaches a heighth of three (3) feet above the level of ground, when further excavation will be had by removing the material within the curb and under the shoe and allowing the shoe to settle from the superimposed weight of the curb. The excavation under the shoe to be carried down uniformly all around to maintain a true level of the last course of brick on the curb. The level shall be taken for each course of brick laid, and when found "out" the curb shall be truly leveled by additional excavation under the higher side. J. W. H.

163. Specification for Turbine Water Wheels.

The following specifications for both horizontal and vertical turbine water wheels was used in the construction of the large water power system of Austin, Texas, of 1892.

Horizontal Turbines. There are to be four pairs of horizontal turbines of 506 horse power each, under 54 feet head. Each pair of these turbines will discharge into one common draft tube. On the shaft of each pair of turbines there will be two pulleys, each to be adapted to transmit the full power of the pair of turbines, and on the same shaft there will be a heavy balance wheel. The pulleys are to be for belt or rope driving as directed. The turbine shafts are to have ample bearing surfaces, and each exterior bearing is to be fitted with oil cups and proper drip pockets.

Each turbine case is to have a man-hole of 10x15 inches clear opening. Each of the turbine quarter-turns is to be of cast-iron and is to be fitted with a good stuffing box and is to be flanged, fitted and bolted to its 5½ feet diameter stop valve. The draft tube is to be flared at its mouth. A cast-iron plate is to be fitted on the floor of each tail race under each draft tube, which plate is to be 6½ feet diameter and raised conically in the center to a point. The floor plates are each to be secured with twelve ¾ inch lag bolts.

The turbine cases, quarter-turns and feeder pipes are to have proper lugs upon them to rest upon the iron beams and masonry, which are to be their supports.

A strong and rigid frame of iron beams is to be furnished with each pair of turbines. Each frame is to be supplied with proper strong hold-down bolts and anchor plates. All anchor rods, plates, lugs and braces are to be supplied that may be necessary to secure the turbine cases, frames, draft tubes and feeder pipes securely in place, so they will be free from movements or vibration.

Vertical Turbines. There are to be also two turbines with vertical shafts, each of 185 horse power under 54 feet head. These vertical turbines will have draft tubes similar to those above described for the horizontal turbines. The draft tubes are to be quarter inch plate iron with seams riveted so as to be air tight and with seams caulked in a workmanship manner. The shaft of each vertical turbine is to extend up to a level proper to receive the beveled pinion at the pump room floor. A pair of bevel wheels is to be furnished with each of the vertical turbines of ratios as directed, approximately 2 and 75-100 to 1. The larger bevel will be a mortise gear wheel with planed mortises and fitted with the best maple cogs which have been thoroughly seasoned and boiled in oil and substantially keyed in place. The small bevel gear will be machine molded and have planed teeth.

The vertical feeder pipe with each vertical turbine and its quarter-turn will be supplied with each wheel case. Within this vertical feeder pipe are to be a sufficient number of bearings to keep the shaft truly in line. These feeder pipes are to be made of quarter inch plate iron of good ductile stock, of not less than 40,000 pounds tensile resistance per square inch, and are to be well riveted with hot rivets and are to be calked water tight in a workmanlike manner.

The quarter-turns will be flanged and fitted with bolts to connect them to the vertical and horizontal feeder penstock pipes or valves. Each vertical turbine is to have ample capacity when working under 54 feet head to start its pair of pumps when pumping at a rate of four million gallons in 24 hours against a pressure of 265 feet of water and to bring the speed of the pumps quickly and easily up to a rate of 25 revolutions per minute.

The turbines will have bronze buckets, approved gates and gate gears, and composition stuffing box glands. Approved cast-iron, bright standard and hand wheels will be set on the main floors of the house, where directed, and connected with the gate gears. Approved, sensitive regulators will be connected with the horizontal turbines. Substantial pedestals will be provided for the bearings of the horizontal shafts.

The turbines are each to be guaranteed to give a duty of not less than 80 per cent. by dynamometrical test, in a testing flume, or by similar test when driving their pumps at a rate to deliver four million gallons of water per 24 hours into the reservoir. *

The turbine cases, turbine and draft tubes, also the vertical feeder pipes of the vertical wheels and all the quarter-turns, are to be set in place in the power house being constructed in Austin, Texas, by the Board of Public Works of the city, and their materials and workmanship, and their trimmings and anchorages are to be of the best of their respective classes, to the full approval of the Engineer, and are to be guaranteed and maintained in perfect condition for the term of one year after their test and acceptance.

A general plan accompanying this specification shows the wheel pits, penstocks, feeder pipes and draft tubes, the floors of the power house and method of using the power. Full detail drawings of the turbines and their appendages are to be delivered to the Consulting Engineer and are to be subject to his approval in all respects. J. T. F.

164. Specification for the Installation of an Electric Lighting Station in a Small City. The following specification for an electric lighting station were prepared in the year 1894, for a small city which required an economical installation. They are given here, not for the purpose of being copied, but as an illustration of what was considered good practice at the time they were drawn. The gentleman who prepared these specifications has had a large experience in Electric Light installation, having been at one time manager of an Electric Works, while at the same time being a mechanical engineer of thorough training and wide experience. The work was to be erected under his own supervision and inspection, so that it was only necessary to make such a specification as would warrant him in demanding first-class materials and workmanship in the execution.

STATION PLANT.

Dynamo: The dynamo shall be of constant potential alternating incandescent type, and to have a nominal or rated capacity of thirty to thirty-five kilo-watts, at one thousand to

*The author recommends that a bonus and forfeiture condition should accompany such a duty clause as this.

one thousand and one hundred volt at station. State number of alterations per minute. Exciter to be belt driven from alternator shaft. By "nominal" or "rated" capacity is meant that load at which the dynamo will run continuously, without undue heating. Proposals will state the capacity, and the amount of overload the machine will safely stand for three hours run in hot weather. Bids are also desired on direct connected generators, with high speed engine of approved design. Bids must give full details, and be accompanied by drawings.

Attachments: Machine to have insulated base frame, belt tightener, self-oiling bearings, automatic regulator, and all necessary station and switch-board apparatus, including lightning arresters. Submit a list of station equipment intended to be furnished.

Regulators: Must automatically control the current over the entire range of the capacity of the machine, without undue heating, or sparking; so that the power required is at all times proportionate to the number of lamps burning. It must provide a steady and uniform light, with variations in the engine speed not exceeding three per cent. The regulators must protect the dynamos in case of short circuiting on the line.

Erection: Contractors will deliver machine, and all station apparatus, and erectsame in position, including substantial foundations of concrete. They will run wires in station between outlet where external construction begins, and switchboard, machines, arresters, exciter, grounds, etc. Wire to Okonite. Furnish and place switch-board, and erect all apparatus thereon. Furnish expert to erect, adjust, and run apparatus ten days, instructing the city's attendants in its care and operation. Contractor must keep informed as to the progress of the work, and arrange the time of his experts accordingly, and there will be no allowance for extra time or traveling expenses, not specially ordered. State charge per day for the time of expert longer than ten days.

Acceptance: Before leaving, the expert must satisfactorily make the capacity test, and such other tests as the city may require to satisfy itself that the provisions of the contract have been fully carried out. At the end of the ten days' run, the apparatus will be accepted, providing the requirements of the contract have been fully met.

Switch Board: Furnish and erect a switch-board, complete, of good, hard, well seasoned wood, providing for one dynamo and two mains for commercial, and for street lights as hereinafter provided. Arrange for easy access to rear of board. Submit list of apparatus to be placed on switchboard.

Lightning Arresters: Include six double pole lightning arresters of approved form for use on the circuits throughout the city.

MISCELLANEOUS APPARATUS AND SUPPLIES.

Converters: From one thousand to one hundred volts. Number and capacity to be as per the accompanying list. Each must be provided with fuse box and eye bolts, or wrought iron straps; with hooks on upper ends to hang directly from cross arm or cleats. The regulation must be within two and one half per cent. for the smallest size, and two per cent. for the largest, besides which, the leakage losses must not exceed five per cent. on the small, and one per cent. on the large, and the regulation and leakage must be uniform for all converters of the same size. Each converter must be ample to carry, in emergencies for three hours continuously, without dangerous overheating, twice its rated capacity, but, of course, with reduced efficiency.

Shunt Coils: Fifty in number; one to be used with each street lamp, of which there are five groups, of ten each. The shunt coils to take care of the current in the event of a lamp burning out. Furnish two extra coils for reserve.

Meters: Will read ampere or watts hours, and must be carefully adjusted and tested before shipment. See list appended. Furnish one extra meter of each of the three smallest sizes.

Lamps: To be of approved make, and furnished with such base as may be selected later. Efficiency fifty-five watts per sixteen candle power lamp. Furnish, now, 1,000 sixteen candle power, and 100 thirty-two candle power. All for one hundred volt current.

Sockets: One thousand of first-class construction, with porcelain base to fit such lamp as may be selected later.

Delivery and Erection: The converters, meters, lamps and sockets shown on accompanying lists and maps, are to be erected in position. The rest of the quantities above named are to be delivered to the city for future use.

Future Orders: The quantities hereinbefore mentioned are to be included in original proposal price, but a price must also be named at which additional orders may be placed within one year from signing contract.

EXTERNAL CONSTRUCTION.

Pole Line.—Furnish and erect in position all poles and cross-arms for the complete distribution system shown on blue print. All poles to be live peeled white cedar, 30 feet long, 6 inches diameter at top, housed and gained for two cross-arms. Set 4½ feet in ground and tamp well. Poles must be straight and sound. Any poles crooking

feet or having more than ten per cent. rot in butt, will be rejected. Location of poles will vary between 100 and 150 feet apart, averaging probably 125. All locations to be approved by city. Furnish 12 extra poles for future use. Furnish all material and do all work, connected with the primary system, starting from station outlet, and including secondaries to house inlets. Corner pins to be 1½ inch extra quality locust, except in cases of unusually severe strain, where they must be of iron; all others 1½ inch painted oak; all wires to be carried on insulators of the deep groove double petticoat pattern.

Wire.—To have triple braided weather-proof insulation of superior finish and smoothness, tough and not easily abraded, and which will not disintegrate or deteriorate by exposure to the elements, and equal in all respects to "K K." The wires will be of sizes as shown on blue print. The drop from converter to house inlet when all lamps shown on map are burning at once must not exceed one per cent.

Street Lights.—Will be 47 of 32 candle power each, run in groups of 10-100 volt lamps, with shunt coils, each group in series. Location of street lamps and wires as per accompanying blue print. All wire No. 10 B. & S. Furnish and erect on switchboard at station, switches controlling all street lights. There will be two groups of 10 street lights each. The other three groups will each have 9 lights on street, and one in station.

Hanging Lamps.—Contractor is to furnish all fixtures, material and labor; to hang in position the 47 incandescent street lamps shown on map, as high above grade line as possible; with cutters suspension street hoods, with cross-arms, insulators, nozzles, and petite pulleys and ¼ inch galvanized iron flexible lamp cord, with hemp core; also galvanized steel wire strand ¼ inch diameter, for suspending lamps in the centre of streets, by the cross suspension method. Use eye bolts with washers for suspension wires, projecting sufficiently to permit slack being taken up by tightening nut. Iron break arms are to be used where lines leave poles, or wherever a loop is made.

Returns from Street Circuits.—Shown in broken lines on blue print may be cut into commercial circuits, instead of returning to station independently.

Incandescent Distribution.—Will be shown on accompanying blue print.

In General.—All joints are to be well soldered and taped. No wire must be lower than 20 feet above grade line. All streets, alleys, and other public places where work is done, must be left in as good condition as before starting. Use special iron brackets wherever necessary, always placing some

soft moisture proof material between the iron screw and the insulator. Erect on incandescent mains where directed, the six lightning arresters.

SECONDARY INDOOR WIRING.

Capacity.—All secondary wiring must be sufficiently large to carry at one time 25 per cent. more lamps than the number shown on the accompanying map, without undue heating, and at 100 volts. The drop from house inlet to the most distant lamp with the above maximum load must not exceed 2½ per cent.

Erection.—All inlets to be in front of houses, except where some other place may be designated, as more convenient. Converters, meters, sockets, and lamps are to be furnished by this contractor, placed by him and connected permanently in position, complete. All other necessary material, such as fuse boxes, switches, cut-outs, etc., to be furnished and erected by this contractor.

Plans.—Name a lump sum for the complete installation of the lamps located on the blue print in accordance with these specifications. State also:

1st. Price per lamp at which this schedule may be added to or deducted from.

2d. Price per lamp which will be charged additional for concealed work.

Character of Work.—Except where otherwise arranged, all interior wiring will be open cleat work, using white double braided painted fire-proof wire. The details of all indoor wiring will be in accordance with the rules of the St. Louis Board of Fire Underwriters. The city will have the work inspected from time to time at its own expense, and any work which may be found, at any time previous to the acceptance of the plants not in accordance with those rules, must be put into satisfactory shape by this contractor at once. Drops to be No. 16 cotton flexible cable, with adjusting ball and fibre socket bushing.

Special Work.—The city grants the contractor the right to sell shades, fixtures, etc., and to do concealed and fixture wiring, for which extra work the customers will pay him direct, such work to be done under the supervision of the engineer, and to his satisfaction.

W. H. B.

165. Specifications for Electrical Distribution Circuits for Light and Power. The following is the descriptive portion of a set of specifications for electrical distribution for light and power prepared for the city of Austin, Texas, in 1894. They are thought to be a good example of

such specifications and are here inserted exactly as used in the letting of the contract.

Power Station: The power station is located at the new dam in the Colorado river and is about three miles northerly of the corner of Congress avenue and Pecan streets in said city of Austin. There will be in the power station one 180 kilo-watt tri-phase generator adapted to generate alternating currents of 2,700 volts potential, two 100 kilo-watt generators adapted to generate direct currents of 550 volts potential, four alternators of 3,000 light capacity, and two alternators of 1,500 light capacity adapted to generate alternating currents of 2,200 volts potential and two arc machines each of capacity to supply currents for 100 arc lamps of 450 watts each.

The wires for power currents will be led out of the station for grouping on one set of poles and the wires for lighting currents for grouping on another set of poles. The currents of the three power generators will be transmitted by three-wire complete circuits.

All the wire circuits are to be connected with the switchboard and station apparatus so as to give the most complete switching, testing and regulating facilities with the least drop of potential consistent therewith. The leading wires are to be strung from the switch-board to the cupola of the power house and out through the panels of the cupola and are to be insulated from the building and panels in the best manner.

All the wires within the buildings will be covered with a firm water proof insulating material, such as shall be approved by the engineer, and to the safe insulation of currents with standard potentials of 2,500 volts.

Pole Lines: The line poles will be of peeled, white northern cedar. The poles are to be straight, sound, smooth and free from large or loose knots that might weaken them.

The dimensions of poles shall not be less than those stated in the following schedule and poles of each representative class are to be set at depths not less than those stated in the schedule, if set in earth, and six inches less if set in solid rock.

Poles will not be less than the schedule thickness at one half foot below their tops, and will be made roofed at their tops and their roofs will be painted with the best quality of mineral paint. Their lowest cross arms shall be at least 18 feet and 3 inches at center above the center of the street opposite the pole.

On the main two-feeder lines, between the power house and Congress avenue, the poles are to be spaced not exceeding 100 feet between centers, and on the sub-feeder and distribution lines poles are to be spaced not exceeding 132 feet between centers, and if lengths of blocks are such that three poles per block

exceed this limit, four poles per block are to be used. Poles will be placed in the curb line or in a line parallel with the curb line if on streets and, if in the alleys, as directed by the engineer.

Corner and terminal poles and all other poles subject to extra unbalanced strains shall be securely guyed with No. 6 galvanized steel wire. Guys shall be so placed and secured as not to be obstructions or nuisances.

SCHEDULE OF MINIMUM DIMENSIONS OF POLES.

CLASS.	Number of cross arms.	Minimum length of poles.	Depth set in earth.	Height of lowest arms.	Dia. at top of poles
A	One.	25 ft. 0 in.	4 ft. 0 in.	18 ft. 3 in.	4½
B	Two.	25 ft. 0 in	4 ft. 8 in	18 ft. 4 in.	5
C	Three.	27 ft. 0 in.	4 ft. 6 in	18 ft. 5 in	5½
D	Four.	29 ft. 6 in	5 ft. 0 in.	18 ft. 9 in.	6
E	Five	31 ft. 6 in	5 ft. 6 in	18 ft. 7 in	6½
F	Six.	33 ft. 6 in.	5 ft. 9 in	18 ft. 8 in.	7
G	Seven.	35 ft. 0 in	6 ft. 0 in	18 ft. 3 in	7½

Gains shall be cut in the poles so that the cross arms will fit snugly and rest at right angles to the axis of the poles. Proper gains are to be made to receive lightning arresters, transformers and other apparatus to be attached to the poles.

The contractor shall secure all necessary permissions for the trimming of private trees and shall do all trimming, and he shall secure the necessary permission for attaching any guy wires to private property.

Cross Arms.—The six-pin cross arms shall be four and one quarter by five and one fourth inches section, and other cross arms of three and one quarter by four and one quarter inch section, and all are to be of sound clear and smooth seasoned white oak. The two-pin cross arms will be of clear, hard Michigan white pine.

Each will be rounded on its top and each will be fastened with three and one half by seven inch bolts [illegible] with washers. The six-pin arms will be not less than five feet and ten inches long and four-pin cross arms not less than four feet ten inches long. All cross arms will have one good coat of the best "P. and B." paint compound for the purpose before being fastened to the poles.

The vertical distances between centers of cross arms shall not be less than twenty inches.

All four and six-pin cross arms will be braced with one quarter by one and one half inch rolled iron galvanized braces, not less than twenty-six inches long on the six-pin arms and twenty inches long on the shorter arms.

Each pair of braces will be secured with two lag screws, two by five-sixteenth inches, and one lag screw three by five-sixteenth inches dimensions each, with washers complete.

Pins.—All cross arms carrying No. 1 or larger wire will be furnished with the best quality of locust pins and for smaller wires with the best quality of white oak pins all with one and and one half inch diameter tenons. The interior pins shall be eight inches from centers of cross arms and other spacings of pins 12 inches between centers.

The pins shall be covered with "P. & B." paint compound, shall fit closely in the cross arm mortises, and shall be secured with steel nails.

Insulators.—Each pin shall have one of the best deep groove glass insulators of double petticoat pattern.

Pole Steps.—Screw pole steps of five eighths by eight inch wrought iron, galvanized, shall be placed on each pole on which there is a lightning arrester, transformer or cut-out. The lowest step shall be at eight feet from the ground and other steps at eighteen inches between centers vertically, but alternately on the opposite side of the poles.

Wire Circuits.—All of the circuits are to be of pure copper, of at least 95 per cent. conductivity, drawn true to gauge and of the best quality in every respect as electrical conductor wires.

The diameters of the circuit wires as herein described are stated in the dimensions of the Brown & Sharp gauge. The wires in the power house will have the best water proof insulation. The wires in all alternating current feeders and circuits are to have the best weather proof insulation of standard double braided and compounded coverings.

The arrangements of the power circuits on the poles from the power station to West Avenue are shown on an accompanying plan and the arrangements of the main alternating circuits and arc circuits are similarly shown on another plan.

On the top of the two main pole lines above described there will be one guard or protection galvanized iron standard barbed double fence wire to be strung on pony insulators, and effectively grounded at distances not exceeding 500 feet.

All joints in wires must have full and durable contact and be soldered in the best manner so that the joints shall hold and maintain a degree of conductivity at least equal to that of the wires connected. All joints so made shall be thoroughly washed in an acid neutralizing solution and well wrapped with insulating tape, and the finishing end of the tape shall be wrapped with copper wire. The insulation resistance of the joint is to be equal to the insulation resistance on other parts of the line.

The power, arc and alternating circuits within the city will be arranged, as nearly as possible, as shown on the accompanying maps of the distribution system

The commercial and domestic lighting by alternating currents will be divided into eight districts, as shown on the wiring map, and the wires will be proportioned for 16 candle power, alternating lamp transformers in each district as follows:

District	No.	1,	1500	Lamps	and	1200	Lamp	capacity	of	transformers.
"	"	2,	3000	"	"	2400	"	"	"	"
"	"	3,	3000	"	"	2400	"	"	"	"
"	"	4,	1500	"	"	1200	"	"	"	"
"	"	5,	1500	"	"	1200	"	"	"	"
"	"	6,	1500	"	"	1200	"	"	"	"
"	"	7,	1500	"	"	1200	"	"	"	"
"	"	8,	1500	"	"	1200	"	"	"	"

The power generators will have their currents wired from the power house into the city by the Boulevard and Pecan street, to Red River street, and a branch current wire will extend along the alley between Congress avenue and Colorado street from 3rd to 10th streets. The transmission will be by three-wire circuits with complete returns, and the drop in potential in full power of the generators shall not exceed ten per cent.

Towers.—Thirty iron "Star" lighting towers of the Detroit pattern, 150 feet each in height to top of mast, are to be located in various parts of the city as shown in the accompanying maps of lighting towers. These towers are to be of the most substantial construction, substantially guyed, and equipped with six 450 watt arc lamps each.

Each of the two circuit systems of wires for lighting these tower arc lamps is to be of No. 6, weather proof, insulated copper wire, connected with the switch board in the power house.

Potentials.—In the wires for commercial and domestic lighting by alternating currents, the loss by drop in potential in the mains between the power house and West avenue shall not exceed twelve and one half per cent., and in the sub-feeders and branches shall not exceed an additional five per cent

Transformers.—The schedule of transformers or converters as herein contemplated is as follows:

Twenty-one of	12 Lamp Capacity, 50 watts per lamp.
Ninety-nine of..................	25 Lamp Capacity, 50 watts per lamp.
Forty of	50 Lamp Capacity, 50 watts per lamp.
Fifteen of..................	70 Lamp Capacity, 50 watts per lamp.
Fifteen of..................	90 Lamp Capacity, 50 watts per lamp.
Eleven of	125 Lamp Capacity, 50 watts per lamp.
Twelve of..................	250 Lamp Capacity, 50 watts per lamp.
One of	300 Lamp Capacity, 50 watts per lamp.

The said party of the first part hereby reserves the right to exchange converters by sizes, taking an equal capacity in smaller

converters as the interest of its patrons shall require. The converters, as located by the engineer, are to be fully connected in the wiring circuits ready for attaching the domestic and commercial wires.

Grounds.—Effective grounds are to be prepared for each of the lightning arresters and for the ground connections of the guard wires. When no good ground connection is available one is to be prepared by placing two bushels of good coke or charcoal near the base of a pole and placing therein a copper plate, one eighth by four inches in section and three feet in length, and the ground wires are to be soldered thereto.

Apparatus.—All the circuits will be fully equipped with the requisite installation apparatus required for the safe and easy operation of the lines and for their testing, inspection and maintenance, such as feeder boxes, primary switch and fuse boxes, cut-outs, transformers, etc., each marked with their safe ampere carrying capacity, and all lines will be fully equipped with lightning arresters.

Each piece of this apparatus is to be located as directed, is to be of the best material and workmanship for the purpose and is to be set and secured in the best manner, and each is to be subject to the rigid inspection and test, and to the approval and rejection of the engineer.

Guarantees.—All apparatus, materials, and workmanship herein specified and contracted for are, by the said party of the second part, hereby guaranteed against all electrical and mechanical defects, and defective workmanship for the space of one year from and after their completion and acceptance. The party of the second part also hereby guarantees that any of the lighting towers herein contracted for, when provided with six direct current arc lamps of 450 watts capacity each (2,000 nominal candle power) will illuminate any portion of a circle 3,000 feet in diameter, of which the tower is the center, sufficiently so that any ordinary watch may be read on the darkest night when the said towers are illuminated. J. T. F.

PART IV.

Illustrative Examples of Complete Contracts and Specifications.

EXAMPLES OF COMPLETE ENGINEERING SPECIFICATIONS, SO FRAMED AS TO INCLUDE THE CONTRACT AND BOND, TOGETHER WITH ALL THE GENERAL CLAUSES, SO DRAWN AS TO BE DISTINCT AND SEPARATE FROM THE SPECIFICATIONS.

166. Contract and Bond Combined in One Document with the Specifications. It is often customary for corporations doing a great deal of work by contract to have a standard form of combined contract, specification, and bond, in which the contracting and surety clauses remain the same, and in which a large proportion of the general clauses remain unchanged, while the specifications proper vary in accordance with the different classes of work to be done. Of such an example is that given in the following article, this being the standard form used by the city of St. Louis. It will be noted that in this contract, the contractor is represented as the party of the first part, and the city of St. Louis as the party of the second part. In Part II of this work, wherein the general clauses of specifications were discussed, the party of the first part was supposed to indicate the employer, and the party of the second part, the contractor. It is, of course, a matter of indifference as to which custom is followed, so long as the doc-

In all the examples given in this portion of the work, the subjects of the clauses will be indicated by marginal titles. This is the common practice in all specifications, but it has not been followed in the previous portions of the work, since the examples chosen were fragmentary in their character, and did not seem to require this kind of indexing. In actual practice, however, it is advisable to use these marginal titles for convenience of reference. So also should the clauses be all numbered, as is done in the examples which follow, these numbers also having been omitted in the previous portions of this work, because of their fragmentary character.

167. Contract and General Specifications for Large Pumping Engines. The following complete contract and specifications was used in 1894 by the Water Commissioner of the city of St. Louis, in the letting of contracts for two large high service pumping engines. They are what is known as general specifications, since they do not indicate any particular style of engine, and since no plans were drawn for the work. It should be understood also that the city of St. Louis is obliged to let all public work by contract and always to accept the lowest bid or to reject all bids. It has hitherto been customary for this city to prepare detail plans for all public work because of this provision requiring them to accept the lowest bid. These specifications have therefore been drawn with the greatest care, and in such a way that the city may be able to accept the lowest bid without danger of obtaining an inferior product. The gentleman who prepared these specifications is a thorough civil and mechanical engineer of about twenty years experience in the designing and operation of pumping engines, and therefore the requirements here embodied are likely to represent the latest and best practice. They are given here, however, not for the purpose of being copied, but for the purpose of illustrating the care and foresight required in the letting of contracts under general specifications, in order that

all the bidders may be placed on an even footing, and that even the lowest bid shall of necessity correspond to a first-class and in every way satisfactory result. In general, where it is obligatory to accept the lowest bid, it is advisable to have detail plans prepared. The privilege had been specially reserved, however, in the advertisement of this work, to reject all the bids, if none of them proved satisfactory, but the city is not allowed, under its charter, to reject a lower bid, and accept a higher.

Referring to clause D in these specifications and to the last portion of that clause, the wording here is evidently too inclusive. That is to say, the Water Commissioner would not be allowed by law to "decide all questions which may arise relative to the execution of this contract on the part of the contractor," with the condition that "his estimates and decisions shall be final and conclusive." See articles 12 and 13, part I, and article 109, part II, for a discussion of this question.

168. Contract and Specifications *for designing, furnishing and erecting at High Service Pumping Station No. 3, St. Louis, Mo., Pumping Engines Nos. 7 and 8, with Fixtures and all Appurtenances Complete.*

A AGREEMENT made and entered into this ——— day of ———————, 18—, by and between ———————————, part of the first part, and the City of St. Louis, party of the second part, *witnesseth:*

WHEREAS, The Board of Public Improvements of the said City of St. Louis, under the provisions of Ordinance No. 17006, approved December 30, 1892, and by virtue of the authority vested in the said Board by the Charter and general ordinances of the city; did let out unto the said ——————— the work of designing, furnishing and erecting, at High Service Pumping Station No. 3, St. Louis, Mo., Pumping Engines Nos. 7 and 8.

———————————

———————————

B *Now, therefore,* in consideration of the payments and covenants hereinafter mentioned to be made and performed by said second party, the said

———————————————— hereby covenant and agree to furnish and erect in the pump pits at High Service Pumping Station No. 3, two pumping engines, each of a capacity of ten million U. S. gallons of water in twenty-four consecutive hours, with all fixtures and appurtenances complete, and in conformity to the requirements and conditions hereinafter specified.

Wherever the words "Water Commissioner" are used herein, they shall be understood to refer to the Water Commissioner of the City of St. Louis, and to his properly authorized agents, limited by the particular duties entrusted to them. C

Wherever the word "Contractor" is used herein, it shall be understood to refer to the part who ha entered into the contract to perform the work to be done under this contract and these specifications, or the legal representative of such part .

To prevent all disputes and litigation, it is agreed by and between the parties to this contract that the Water Commissioner shall, in all cases, determine the quantity and quality of the several kinds of material to be furnished and work to be done, the duty and capacity of the engines, and the amount to be paid under this contract; and he shall decide all questions which may arise relative to the execution of this contract on the part of the Contractor, and his estimates and decisions shall be final and conclusive.* D

The said part of the first part hereby agree that all materials and workmanship, of whatever description, shall be subject to inspection and rejection by the Water Commissioner, and that the entire work shall be done to his satisfaction. The said part of the first part further agree that the Water Commissioner may appoint such assistants as he may deem necessary to inspect the materials to be be furnished and the work to be done under this agreement, and see that the same strictly correspond with the specifications hereinafter set forth; and that said Water Commissioner shall at all times have the right to enter the works, shops, etc., where the machinery is being constructed, for the purpose of inspection and examination of the materials furnished and work being done, and shall be afforded such assistance as may be required to determine whether the quality of the materials and the character of the E

*This last provision, that the Engineer sha[illegible] "all questions" which may arise, is not binding. See Art 13 [illegible] 19

work are in accordance with the requirements and intentions of this contract.

F The part of the first part further agree that the materials used throughout the engines and appurtenances shall be of the qualities specified, and new and unused when put into the work, and that the engines and appurtenances shall be constructed and erected in the most workmanlike and substantial manner, and everything done and furnished necessary to complete and perfect the engines and appurtenances according to the designs and intentions of this contract, whether particularly specified or not, but which may be inferred from the drawings and from this contract and the following specifications:

SPECIFICATIONS.

Work to be done.

1. The work to be done consists in making the design, furnishing general and detail drawings, constructing and erecting complete in place ready for service at High Service Pumping Station No. 3, St. Louis, Mo., two vertical triple expansion condensing pumping engines. Each engine shall pump ten millions U. S. gallons of water in twenty-four hours.

GENERAL DATA.

Water Pressure	125 pounds.
Steam Pressure	125 pounds.
Elevation Bottom Pump Pit (City Datum 100)	90 feet.
Elevation Engine Room Floor	118 feet.
Elevation Water in Wet Well (Approximate)	110 feet.
Dimensions of Pump Pit	56x57 feet.

PLANS.

Working detail plans.

2. A complete set of accurate and distinct detail working tracings, made in accordance with the general plans submitted by the Contractor with his proposal and approved by the Board of Public Improvements, shall be furnished by the Contractor and submitted to the Water Commissioner within four months after the award of the contract.

3. The tracings shall be of uniform size—25½ x39 inches—and shall have a clear margin of at least ⅜ of an inch.

4. The kind of material to be used in each and every part of the construction shall be clearly denoted in the tracings by different section lining or by distinct lettering.

5. The tracings shall show complete sectional outline and plan views, giving all necessary dimen-

sions and thickness of metal, radii of fillets and roundings in the various parts of the construction in plain and intelligible figures, and shall definitely state in printed letters, at all surfaces and details, the name of the parts and the kind of machine work and finish to be put upon them, thus enabling the machinery to be built and completed exclusively from blue prints taken from the tracings.

6. There shall be separate tracings showing the valve motion, as put together in working condition.

7. The tracings will be examined by the water commissioner, and if found in accord with this contract and specifications, will be approved; any change found necessary shall be at once made by the contractor to the satisfaction of the Water Commissioner. To be Approved.

8. The contractor shall also, within two months after the award of the contract, furnish accurate and workmanlike general tracings, made in accordance with the drawings submitted by the contractor with his proposal, and filed in the office of the board of public improvements, and with the detail drawings approved by the Water Commissioner. General Working Plans.

9. These general tracings shall show the position of the engines in the pits, with all required foundation piers and bolts, and all floors, girders, platforms, stairs, galleries, railing, pipes, stop valves and all appliances complete, giving all general dimensions required in the erection of the machinery.

10. If, during the construction, it be found expedient or necessary to change or modify the design of any of the details of the engines, working drawings showing the proposed changes shall be submitted to and approved by the Water Commissioner before any change is made. Change of Design.

11. All drawings rendered in any way incorrect through changes or modifications, must be completely replaced by new tracings.

12. Before the final payment for the engines, the contractor must furnish and deliver to the water commissioner a book of complete general and detail drawings of all parts of the engines and appurtenances, as built and erected. Book of Finished Drawings.

The detail drawings shall show all details entering into the construction in sectional, outline and plan views, with all dimensions plainly written in neat and intelligible figures and names printed at

every detail, the kind of material used and the finish of the various parts and surfaces.

The general drawings shall show the engines in position in the pump pits in at least four different views, viz.: Sectional side elevation, sectional end elevation, contour or outline end elevation and plan, and shall give necessary main dimensions, thickness and kind of metals, location of foundation bolts, and all important sizes of the machinery as erected.

These general and detailed drawings shall be made on mounted double Elephant paper of a size of 25½x39 inches inside the margin lines, strongly and substantially bound in book form, with the name and date of the engines printed in gilt letters on the covers of the book.

All drawings shall be accurately and neatly executed in ink in a workmanlike manner and to an appropriate scale. All sheets shall be uniformly lettered and consecutively numbered and provided with proper titles and headings.

DESIGN.

General Features.

Pit. 13. The two engines shall be designed to be erected and operated independently in the south pit of the engine house, which will be built by the city of St. Louis, substantially as shown by the plans on file in the office of the water commissioner.

Especial attention must be paid to the fact that the engines will be used for direct pressure service.

14. Engines shall have ample space around all their various parts for access and maintenance.

Suction. 15. The height of the water in the wet well will depend upon height of water in conduit, which will be approximately constant.

Steam. 16. The engines shall be designed for an initial steam pressure of 125 pounds per square inch and a water pressure of 125 pounds per square inch.

Plunger. 17. The pumps shall be designed and constructed to deliver the stipulated quantity of water at a plunger speed which will insure a smooth and effective action of the pump valves, and all working parts of the machinery, but in no case shall the diameter of any pump plunger exceed 40 per cent. of its stroke, or the plunger speed exceed 180 feet per minute.

Balanced.

18. The arrangement and construction of the ngines shall be such that they will give equal steam ards on the up and down strokes.

Reliability, etc.

19. The engines shall be designed and pro-portioned to have great working strength, stability nd stiffness, and ample space around all parts for rection, repairs, lubrication, inspection and adjust-nent.

Vertical.

20. The steam cylinders and the plungers of he engines shall be vertical.

Height.

21. The steam cylinders and the regulating nechanism of the cut-off and valve motion shall be laced entirely above an elevation of 120 feet above latum.

Frame.

22. The pump chambers and steam cylinders hall be rigidly connected and supported through he intervening frames and columns to make the vhole construction of ample stability, strength and tiffness.

Plungers.

23. Each engine shall have vertical, single cting outside packed plungers, and no construction vill be allowed requiring internal stuffing boxes, lands or water packings in the pumps. All stuffing oxes shall be readily accessible for inspection and ightening up, while the engine is running.

Removal of Parts.

24. The machinery shall be so constructed, upported and arranged that the pump chambers or ny important part or piece of the substructure can e easily removed to such position that it can be oisted out of the pump pit without necessitating the rame and fixed parts of the superstructure of the nachinery being taken apart, disturbed or removed.

Condenser.

25. The two engines shall each be provided vith a surface condenser, of appropriate size and onstruction to maintain a steady vacuum, and esigned to directly utilize the water discharged by ne main pumps for condensation of the exhaust team.

Attachments and Appurtenances.

26. The contractor shall furnish and put up ll pipes, valves, oil cups, drip pans, fittings and xtures required to make the construction complete nside the engine room and pump pit, and shall urnish flanges drilled for connection on end of ipes near wall.

Appearance.

27. The various parts of the machinery shall e of plain shapes and forms, adapted to their

specific purposes, insuring great strength and reliability with good mechanical effects.

Frame and Fixed Parts.

Expansion. 28. The frame and foundation of the engines shall be so designed that changes of temperature can not alter the distribution of the loads on, or affect the alignment of the members of, the frame, and, where necessary, expansion joints shall be used.

Frame. 29. The frame of the engine shall be designed to have great stiffness and weight, so that it shall withstand all working stresses with the minimum vibration. All bed plates or sole plates resting on masonry shall have ample bearing surfaces to safely distribute the working pressures.

Anchor Bolts. 30. the machinery shall be substantially and securely anchored and held in place with a sufficient number of foundation bolts.

Castings. 31. All castings shall be designed to avoid sudden changes of section and of such forms as will cool uniformly without shrinkage strains.

32. At all flanges of castings there shall be a reinforcement, or addition of metal, of at least 30 per cent. of the regular thickness, which shall extend in length or height at least twice the total thickness of the metal at the reinforcement. All flanges to be of not less thickness than the total metal at the reinforcement.

33. All castings must have good sized fillets at all corners; no small brackets will be allowed.

Reheaters. 34. If reheaters are used they shall be designed and constructed to be absolutely steam tight under all working conditions to which they will be subjected, and must have proper heating area and space and facilites for examination, repairs and renewals.

Jackets. 35. If steam jackets are used they must be secured to the steam cylinder in such a manner as to allow free and easy expansion and contraction, without causing internal leakage of joints or derangement of any description to jackets or cylinders, or undue strains in any part; and must be arranged to insure proper circulation of steam and ready removal of the jacket water.

36. All flat plates and surfaces acted upon by water pressure must be substantially proportioned and strengthened with a sufficient number of heavy ribs, to make them of ample stiffness and strength to

safely carry the loads to which they will be subjected.

37. All handholes and manholes shall be of ample size, well fitted, and so constructed as to be readily opened and closed.

38. Priming and draining pipes and valves shall be provided for filling and emptying the pump chambers.

Condenser.

39. The condensers must safely stand all working stresses to which they may be subjected, without leakage or weakness of any description.

Examinations and Repairs.

40. The condensers shall be constructed to give ample facilities and space for the examination, insertion and withdrawal of tubes and packing of joints. The tubes must be provided with perfectly tight and easily removable packings, allowing for expansion and contraction, without injury or leakage.

41. The condensers shall be so arranged that the amount of water passing through, or condensing surface, can be adjusted to suit varying temperatures.

42. Arrangement must be made for proper distribution and circulation of the exhaust steam and condensing water on the cooling surfaces of the condenser, without injurious impingement of the steam or condensing water.

43. All glands and washers used in the condensers shall be made of composition; all bolts and nuts (except stay bolts) used inside the condensers shall be made of Tobin bronze.

44. The condensers must be provided with all necessary auxiliary pipes, valves and tanks.

Hot Well.

45. The hot well shall be set at the highest elevation in the pit which the design of the engines will permit.

46. There shall be effectual means and apparatus provided for the separation of grease and oil from the condensed water before it is fed to the boilers.

Suction and Discharge Pipes.

47. The suction and discharge pipes shall be thirty inches in diameter.

48. For each engine there shall be a single suction or inlet pipe, which shall be attached to the gate valve, furnished by the City of St. Louis, shown in the plans of the pump pits.

49. The discharge pipe for each engine shall be carried up to an elevation of 113.6, and then horizontally through and to a distance of two feet from the outside of the pump pit wall, and shall be provided with a drilled flange for connection to pump main.

Air Chambers. 50. Each engine shall be provided with air vessels of sufficient capacity to insure smooth, easy and equal action of the pumps.

By-pass. 51. Each engine shall be provided with a by-pass pipe, arranged to facilitate draining the pump mains and starting the engines.

Relief Valves. 52. Each engine shall be provided with a pressure relief valve designed and arranged to by-pass the discharge of its pumps when the pressure on the pump mains exceeds 125 pounds per square inch.

53. The pressure relief to be of sufficient capacity to by-pass total discharge of the engine.

54. There shall be platforms or galleries of cast iron plates or wrought iron open work at convenient locations upon the pump and steam ends, which will allow all of the operations necessary in running and maintaining the engines to be performed with the greatest safety and ease.

55. The Contractor shall design, furnish and erect iron stairways, landings and galleries leading from the top gallery down to the bottom of the pump pit, with all intermediate galleries and supporting girders, beams, and composition railings required to make them complete and satisfactory in all respects. All of the above to be made of neat and harmonious proportions, and arranged to leave sufficient space for hoisting and removing the pump chambers and other parts of the machinery without disturbing any beams, bed-plates or other stationary parts, or necessitating the removal of stairways, landings or galleries to any great extent.

Light. 56. The galleries, stairs and platforms shall be arranged to secure as good diffusion of light down the pump pit as possible.

57. The stairs to be made without risers. Tread plates and all gallery plates to be made of a suitable open-work pattern.

All parts of stairs, galleries and platforms shall be accessible for inspection and painting.

Mechanism and Wearing Parts.

Strength and Stiffness. 58. All moving parts shall be of ample strength and of sufficient stiffness to prevent undue vibrations in operation.

Wearing Surfaces. 59. All journals and wearing surfaces shall be of sufficient size and of proper proportion to avoid excessive pressure and heating.

60. When practicable, provision shall be made to prevent the wearing of shoulders on either stationary or moving parts at their extreme travel. Counter-boring.

61. All stationary journals shall have suitable boxes, babbitt lined when necessary, and all journals above four inches in diameter shall have provisions for horizontal and vertical adjustment. Journals.

62. All glands and guide rings of stuffing boxes shall be provided with composition linings forced in and securely held in place, and the glands shall be cupped out to make proper receptacles for lubricants, leakage water, etc. Bushings.

63. The bodies of all valves, three inches in diameter and smaller, shall be entirely of composition, but the bodies of valves larger than three inches, may be of cast iron, with composition valve and valve seats. Valves, etc.

64. All valves, fittings, fixtures and appurtenances used, shall be of an approved design.

65. The valve motions and starting arrangements of the engines shall be such that each engine can be promptly and safely started and operated by one engineer. Steam End

66. The steam distribution valves shall be of a known reliable type. They shall be well balanced and so designed as to work with the minimum friction, to wear even and steam-tight, and to have proper facilities for refitting and adjustment. Valves.

67. The steam valve mechanism shall be of ample strength and durability, and must be reliable in all its motions and entirely free from any danger of failure, derangement or rebounding. The engine and valve mechanism to be provided with an automatic device to prevent racing in case of a broken pump main. Valve Motion. Regulation.

68. The engines shall be fitted with a variable cut-off mechanism so arranged as to be easily and quickly adjusted while the engines are in operation. Cut-off.

69. The running throttle valves of the engines shall be of a well-balanced type and operate quickly and easily under full steam pressure. Throttle.

70. The steam pistons of the cylinders shall be provided with Babbitt and Harris piston packing, packing which, in the opinion of the Water Commissioner, is equally efficient. Pistons.

71. Steam valves above six inches in diameter shall have steel stems provided with Phospho bronze nuts.

Pump End

72. The area of the suction and discharge valves shall be sufficient to insure proper filling and discharging of the pumps under all conditions, but in no case shall the total suction valve area, or the total discharge valve area of each engine be less than 6 square feet.

Valves.

73. The valves shall be designed and constructed to open and close promptly and quietly, shall be tight and of ample strength, and shall be especially designed for facility of repairs and renewals.

74. All valve stems of stop and gate water valves shall be made of Tobin bronze.

Connecting Pieces.

75. All connecting, piston, plunger and distance rods, and all movable parts must be of ample strength and stiffness to withstand all working stresses.

Guides.

76. The piston rods, plunger and plunger rods, and all reciprocation parts have properly designed guides and crossheads. The crossheads shall have shoes adjustable for wear.

Boxes

77. All journals and pins of connecting and valve rods, and of all reciprocating and oscillating rods, shall have well proportioned strap or box ends having easily removable composition boxes, Babbitt lined where required, and provided with wedges, keys or bolts for adjustment of wear. Each link or connecting rod shall at the different ends, have provisions for compensation of wear in the same direction

78. All strap or box ends shall be of a shape having great strength and stiffness, holding the composition boxes securely, and giving a neat and workmanlike appearance.

Locked Nuts

79. All nuts of pillow block caps bolts and follower bolts of pistons, all screw joints of moving parts and all keys shall be provided with a secure locking device.

Fly Wheel

80. If a fly-wheel is used, the shafts shall rest in pillow blocks very securely and rigidly supported at ample distances apart.

Air Pumps.

81. The construction of the air pumps must be such that they will at all times perform their work promptly without noise or injurious shocks.

82. The air pump and all accessory pumps required to run the engine, except the boiler feed pump, shall be driven from the main engine.

MATERIALS.

83. All materials used throughout this construction must be of the special class and grade called for in the specifications and designated in drawings, and shall in each case fully stand the specified tests.

84. All castings shall be free from blow holes, flaws, scabs and defects of any description, and shall be smooth, close grained, sound, tough, and of true forms and dimensions. Castings.

85. All casting must be done in accordance with the best modern foundry practice to obtain castings of the very best quality. Castings above 500 pounds in weight shall be moulded in dry sand or loam. Great care must be taken to make all castings as nearly as practicable of uniform thickness throughout.

86. No plugging or other stopping of holes or defects of castings will be allowed.

87. The cast iron used in the steam cylinders, the steam distribution valves, the barrels of air pumps and the water plungers shall be close, fine grained, hard and uniform in character and of good wearing qualities. The cast iron used in all other parts of this construction shall be of superior quality, tough and of even grain, and shall possess a tensile strength of not less than 22,000 pounds per square inch. Test bars of the metal 2 inches by 1 inch, when broken transversely, 24 inches between supports and loaded in the center, shall have a breaking load of not less than 2,200 pounds, and shall have a total deflection of not less than 0.35 of an inch before breaking. Cast Iron.

88. The test bars shall be cast as nearly as possible to the above dimensions without finishing, but corrections will be made by the Water Commissioner for variations in thickness and width, and the corrected results must conform to the above requirements. Test Bars.

89. If any two test bars, cast the same day, show a tensile strength less than 22,000 pounds per square inch, or do not show the required cross breaking load or deflection, all the castings made from the melting from which the samples were taken may be rejected.

90. All steel castings used in the construction shall be thoroughly annealed and possess a tensile Steel.

strength of 65,000 to 75,000 pounds, and 15 per cent. elongation in two inches.

91. All steel forgings used in this construction shall be equal to forgings manufactured by the Otis Steel Company, Cleveland, Ohio, and have a tensile strength of not less than 75,000 pounds per square inch of section, and show an elongation of 20 per cent. in eight diameters.

Wrought Iron. 92. All of the wrought iron used shall be tough, fibrous and uniform in character, and specimens broken in the testing machine shall show a tensile strength of not less than 50,000 pounds per square inch, with an elongation of 18 per cent. in eight diameters.

93. If any specimen of steel or wrought iron shall not conform to the above requirements, all material of the lot from which the specimen was taken, will be rejected.

Bolts. 94. The Water Commissioner may take at random any wrought iron bolt and nut, and have it broken in a testing machine. If any two bolts shall not fill the above stipulated requirements for wrought iron, the whole lot of that size and make may be rejected; the effective area used in computing the breaking strength, will be the area corresponding to the smallest diameter at the bottom of the threads, when cut in accordance with the U. S. standard.

Rivets. 95. Rivets shall be made from the best refined iron, and must be capable of being bent cold until until the sides are in close contact without sign of fracture on the convex side.

Shapes. 96. All rolled wrought iron shapes shall be free from twists, bends, seams, blisters, buckles, cinder spots or imperfect edges. All sheet and plate iron must be capable of being worked at a proper heat without injury.

Rods. 97. All rods shall be formed in one continuous rolled or forged piece without weld.

Composition. 98. All the composition metal used [excepting for Tobin bronze and hand railing] shall consist of the best quality, new material only, of mixtures specially adapted for the work in each case, and approved by the Water Commissioner.

Phosphor Bronze. 99. All Phosphor bronze used must be homogeneous and uniform in character, and shall have a tensile strength of not less than 30,000 pounds per square inch, with an elongation of 15 per cent. in eight diameters.

100. All Tobin bronze used must be homogeneous and uniform in character, and specimens broken in a testing machine shall show a tensile strength of not less than 60,000 pounds per square inch, and an elongation of 20 per cent. in eight diameters. Tobin Bronze.

101. Finished bolts and nuts of Tobin or Phosphor bronze may be tested in the same manner as specified for wrought iron, and if any two bolts shall not fulfill the requirements, the whole lot of that size and make will be rejected.

102. Test specimens and samples of castings, forgings, composition or any other material used in this construction, shall be prepared ready for testing and supplied in the number, shape, finish and sizes required by the water commissioner, and shall be prepared as may be directed at any time during the pouring or working of the materials. Test Bars.

For all material taken by the water commissioner for testing, the following prices will be paid, which shall include the cost of preparing and finishing the test specimens, viz.:

For all wrought iron or steel, the sum of ten cents per pound.

For all composition, the sum of thirty cents per pound.

For all cast iron, the sum of three cents per pound.

All broken material to belong to the city of St. Louis.

103. The Babbitt metal used throughout the construction must be of the following approximate proportions by analysis: 88 per cent. pure tin, eight per cent. antimony, and four per cent. Lake Superior copper. Babbitt Metal.

104. All rubber for valves and gaskets must be of a suitable quality, approved by the Water Commissioner before it is used. Rubber.

105. All other material used in the engines and not mentioned in these specifications will be subject to inspection, test and approval by the Water Commissioner before it is used. Other materials.

CONSTRUCTION.

106. The workmanship and finish of the pumping engines throughout shall be equal to the best American practice, and in every respect satisfactory to the Water Commissioner. Workmanship.

Machine Worked.

107. All surfaces worked in machine tools must be true and smooth, and accurately conform to the drawings in shape, size and alignment.

108. The bearing surfaces of all sole and bed plates and parts resting on masonry shall be planed.

109. If fly-wheels are used, the parts shall be fitted and fastened together in the most careful and workmanlike manner and the outer circumferences and the sides of the rim shall be turned smooth and true.

Joints.

110. All joints of bed plate and frame to be planed or faced and carefully fitted.

Boring.

111. The steam cylinders shall be bored in a vertical position, perfectly smooth and truly cylindrical, with a boring bar of proper diameter.

Turning.

112. All circular flanges shall be faced on the outer circumference.

113. All centers of lathe work must be made of ample size and carefully preserved.

114. All corners in journals and elsewhere in turned work shall be rounded to proper radii.

Joints.

115. All steam joints shall be made in an approved manner, with a very thin gasket of Jenkins' Usidurian packing.

116. All water joints to be made with rubber or paper gaskets, arranged with special care to prevent blowing out.

117. All seats of steam and water gates must be scraped and ground tight.

Journals.

118. All journals to be turned straight, cylindrical and smooth. Particular attention and care shall be paid to the proper fitting and scraping of all journal boxes, to make the same of an extraordinarily good bearing surface, and accurate fit to their housings or carrying members.

Straps, etc.

119. Straps, gibs, keys, reamed bolts and boxes of all connecting rods must be fitted with the utmost care and accuracy, and finished in a thorough and workmanlike manner.

Scraping.

120. The final fitting marks shall, for all parts, be preserved for examination and must in all cases be satisfactory to the Water Commissioner.

121. All journal boxes, pins, keys and other details of the machinery shall be taken apart at any time during the process of fitting or erecting, when the Water Commissioner so directs, to allow a thorough examination of fit and workmanship.

122. If gear wheels are used in the valve motion of the engines, they shall be properly designed and accurately cut in gear cutting machines. Gear.

123. The treads of cams and other parts of the valve motion subject to intermittent or sudden motion and heavy wear shall be of tempered steel or case hardened iron. Cam Treads, etc.

124. The tempering or hardening processes must be so conducted that parts will retain their proper size and shapes and have the requisite hardness. Tempering or Hardening.

125. All parts of the engines must be well secured and correctly centered with accurately fitted dowel pins, reamed bolts or male and female joints. Centering.

126. All flanges must be cast solid, and all bolt holes shall be drilled with perfectly sharpened and centered twist-drills to insure accurate round holes. Bolting.

127. All dowel pins must be of proper taper, and well fitted; and where necessary, shall have proper facilities for removal. Dowel Pins.

128. All holes intended to receive tapering parts shall be carefully reamed and ground and the tapering parts driven or forced into place. Taper.

129. Nuts and bolts and all threads shall be of the U. S. standard, except where special threads are necessary. Threads.

130. The threads and shanks of all bolts above 5/8 inch in diameter shall be cut and turned in the lathe, and the ends of all bolts shall be finished to a neat conical or hemispherical point.

131. The resting surface for nuts and heads of all bolts shall be faced to present a smooth, plane surface, square to the axis of the bolt.

132. Case hardened, finished and polished nuts shall be used in all exposed work above the upper floor level, and also for all parts requiring frequent removal and adjusting. All other nuts and bolt-heads above the upper floor level, and nuts for all stuffing boxes, and at such other places as may be necessary, shall be finished. Finished Nuts.

133. Finished Phosphor bronze nuts and rolled Tobin bronze studs and bolts to be used for all fastenings inside the pump chambers, and for all glands of stuffing boxes of the pump end.

134. Cold pressed nuts shall be used for all stationary parts of the pump chambers, and in all cases where not otherwise specified. Cold Pressed Nuts.

Hexagonal. 135. All nuts and bolt heads shall be hexagonal in shape and must be faced on top and bottom. The sides shall fit their wrenches accurately.

Keys. 136. All key-ways and keys must be accurately fitted and properly driven or forced into place, and must be of appropriate size and taper.

137. All riveted work shall be specially designed for its particular uses, and executed in a thorough and workmanlike manner.

Calking. 138. All riveted joints subject to pressure shall be thoroughly and neatly calked with a round-nosed tool.

Finishing. 139. All connecting rods, links and valve rods shall be draw-file finished.

140. All bright and specially finished work must be of the highest grade and entirely free from scratches, specks and flaws.

141. All visible composition work shall have a bright finish.

142. All exposed machine worked surfaces of all parts above the upper floor level and of all moving parts, except fly-wheels, shall have a bright finish.

Lagging. 143. The steam cylinders, steam chests, reheaters, steam and distribution pipe and other heated surfaces of the machinery, when necessary, shall be protected by neat mahogany or walnut lagging, securely fastened and held in place by brass bands and button-headed brass screws, or by bright finished false covers.

Covering. 144. All steam pipes and heated surfaces shall be protected with approved non-conductors to the depth of flanges.

145. The material to be used in covering steam pipes, cylinders, reheaters and all protected parts, and the method of its application, shall be subject to approval by the Water Commissioner.

146. No non-conductors, lagging or false covers shall be applied until the construction has been thoroughly tested by working steam pressure and all leakages and defects developed have been thoroughly remedied.

ERECTION.

In Shop. 147. The Contractor shall erect in the shop such parts of the steam and water ends of the engines as may be necessary, in order that the final erection

can be carried on with despatch in a thorough and workmanlike manner.

148. The Contractor, shall, at his own expense and risk, transport all parts of the machinery to the pumping station, but will be allowed the use of the power traveling crane in the engine house for erecting. Transporting.

149. All foundations and piers required for the support and anchorage of the engines, in addition to that shown in the city's drawings, will be built by the city of St. Louis, to drawings furnished by the contractor. All foundation piers will be built of first-class coursed cut stone masonry and provided with granite capstones of appropriate sizes, and charged to the contractor at $20 per cubic yard. Masonry.

150. The contractor shall deliver at the pumping station all bolts, washers, wall boxes, girders, etc., intended to be inserted in the masonry, in ample time to prevent delay during the building of the foundation walls and piers. Wall Boxes, etc.

151. The contractor shall be responsible for the proper and exact location of all parts, when placed in accordance with his drawings and templets.

152. The contractor shall do all work necessary to erect, fit and secure the engines in the pump pit upon the foundation piers as completed and built by the city of St. Louis. In Pit.

153. Every sole plate, girder, bed plate and casting resting on or secured to masonry, shall be provided with a rust joint of sufficient thickness, carefully driven and packed and consisting of ingredients satisfactory to the Water Commissioner. Rust Joint.

154. Great care shall be taken in the erection of the engines to place and secure the various sole and bed plates upon solid, plane and smooth bearings. All joints between stationary details must be made with the utmost accuracy and precision, insuring perfect and permanent alignment. None of the parts shall be unduly strained in lining up. Bearings.

155. The contractor shall so conduct his operations as not to interfere with the work of other contractors, and the disposal of his tools and materials during storage and erection will be subject to the approval of the Water Commissioner. Other Work.

156. The party of the second part will furnish and set the gate valves of the suction pipes, but the contractor shall pump out all accumulated water in Water.

the pump pit before commencing erection, and do all necessary pumping during erection of engines.

Protection of Parts. 157. All finished parts must be well protected in shops and during transportation to prevent injury and abrasion.

Damage. 158. All injured parts must be replaced, when in the judgment of the Water Commissioner, refitting will not suffice.

Cleaning up. 159. The contractor shall remove all staging used in erecting the engines, and leave the pump pit, engine room and premises neat and clean.

Damage to Masonry, etc. 160. The contractor shall, at his own cost, make good all damages to masonry, buildings, or other property of the city of St. Louis, occasioned by the contractor or his employes in the transportation and erection of the machinery.

Storage of Machinery Parts. 161. The city of St. Louis will furnish space within its premises for the reception of the various parts of the machinery, but shall not be responsible for the safe keeping of these parts, nor for damage caused to them from exposure or other cause.

PAINTING.

162. All castings and details must be inspected and approved before painting, and in no case shall the paint or pitch be applied until all surfaces are trimmed and thoroughly cleaned.

Paraffine Varnish. 163. All unfinished iron work not visible from the engine room floor (except where otherwise required) and that above the floor intended to be encased, shall be thoroughly painted inside and out with three coats of No. 1 paraffine varnish, applied hot. The first coat shall be put on at the shop, and the others after erection, excepting for inside surfaces of pumps, pipes, etc., which shall receive two coats at the shop and one after erection.

Oil paint. 164. All unfinished iron work visible from the engine room floor, shall be thoroughly cleaned, rubbed down and painted with four coats of a good quality of paint and strictly pure linseed oil. The first coat shall be put on at the shop and the others after erection.

165. The paint shall be of a grade and color approved by the Water Commissioner, and shall be applied, striped and varnished to his satisfaction.

166. All parts to be covered by non-conductors must be thoroughly cleaned and freed from rust, and painted with three coats of paint of a kind,

color and quality to be determined by the Water Commissioner before application of the non-conductors.

167. All finished and polished surfaces must be kept entirely free from rust until erected and finally accepted. Finished Iron Work.

TESTING.

168. After erection has been completed, and before the final painting, a blank flange shall be bolted on the out-door end of the discharge pipe, and the whole construction tested with hydraulic pressure. A force pump shall be connected to the discharge pipe, and a pressure of 200 pounds per square inch applied in such manner as to test the pumps, pump valves, air vessels, discharge pipes, pump rods and the frames of the engines. After this test the engine is to be run to full capacity, discharging through the pressure relief valves for the purpose of testing same; a further test to be made by suddenly opening gate on pump main to test speed controlling device mentioned in section 67. Pressure.

These tests must be conducted by the contractor with great care and in a manner satisfactory to the Water Commissioner.

The contractor shall furnish all labor necessary, and all piping, cocks, valves, gauges, force pumps, flanges and appliances required in the tests.

169. For the purpose of determining the duty of the engines furnished under this contract, there shall be an expert duty test of twenty-four hours continuous run for each engine. These tests shall be conducted by three experts, one to be selected by the Water Commissioner, one by the contractor, and the two thus named to select the third. Duty Test.

The duty tests shall be conducted for one engine at a time, unless otherwise ordered by the Water Commissioner.

170. The water of condensation from all steam jackets and reheaters shall be gathered and its weight carefully determined, and it shall be charged against the engines during all of the duty tests.

171. The total weight of water fed to the boilers during the tests, shall be considered the amount of steam used when corrected for entrainment exceeding two per cent.

172. Steam used for running the boiler feed pumps during the duty tests will not be charged against the engines.

Expert Test. 173. The twenty-four hours duty test shall be made with the water in the wet well at an approximate elevation of 110, and shall be conducted by the experts selected in accordance with section 169 of this contract.

Speed. 174. If, in the opinion of the Water Commissioner, the speed of the engines at any time during the twenty-four hours test is such as to jeopardize their safety, he shall have the right to order them run at such reduced speed as will give a smooth and quiet action.

Head (h). 175. The head (h) to be inserted into the formula for computing the duty of the engines during the running test, shall be ascertained by attaching a gauge to the discharge pipe close to where it turns into and runs through the foundation walls of the pit, and by the elevation of the water in the wet well.

176. Any part or detail of the engines showing undue strain or weakness of any description, must be replaced, and all defects developed in these tests shall be corrected by the contractor to the entire satisfaction of the water commissioner.

ADDITIONAL APPLIANCES.

Wrenches. 177. The contractor shall furnish for all sizes of bolts a complete set of wrenches for each engine, accurately fitted to the respective sizes of nuts. The wrenches for all finished nuts about the engines shall have a bright finish and shall be marked with their respective sizes.

178. Each engine shall be provided with one steam gauge, graduated from 0 to 250 pounds, one vacuum gauge, one suitable steam gauge on each receiver (if such be employed in the construction), and one engine revolution counter; all of them to have brass cases, triple silver plated, and placed convenient for observation. The dials of gauges to be ten (10) inches in diameter.

179. Each of the air vessels of the pumps shall be provided with one glass water gauge of satisfactory design. The hot well for each engine shall be provided with a suitable, permanently attached thermometer of appropriate design.

180. The contractor shall furnish one steam indicator for each steam cylinder and three indicators for the main pumps, and one indicator for the air pumps. The indicators shall be the Thompson, Crosby or Tabor. Indicators.

181. Each steam cylinder, main and air pumps of the two engines shall be provided with permanent piping, fixtures and motion appliances for attaching and working the indicators. All valves, cocks, pipes and appliances for the attachment of the indicators to the steam cylinders and pumps shall be made of composition, of ample size and complete in every respect.

182. All journals must be provided with sight-feed oil cups. There shall also be brass drip pans or pockets at all journals and oiling places to catch lubricants. Oil Cups, etc.

183. The steam cylinders shall be fitted with sight-feed lubricators.

184. There shall be valves, pipes and drip pans at all places where necessary, for receiving and conveying water from stuffing boxes, etc.

185. The contractor shall furnish an extra set of suction valves and an extra set of discharge valves with all parts complete.

REPAIRS.

186. Near the end of the year of probation, the Water Commissioner will make an examination of the engines, and any part or detail found to be defective or injured through excessive wear, overstrain, bad material or faulty design, shall be replaced by the contractor, at his own cost and expense, to the satisfaction of the water commissioner.

The said part of the first part further agree that all the work contemplated and described in this contract and the foregoing specifications, shall be done in accordance with the general drawings approved by, and on file in the office of, the board of public improvements, and with the detail working drawings submitted to and approved by the Water Commissioner. It is further agreed that the drawings and specifications form a part of this contract, and that, if any discrepancies appear between any of the drawings and the specifications, or between any of the several drawings in themselves, such discrepancies shall be adjusted by the contractor to the satisfaction of the Water Commissioner. And it is G

further expressly agreed that the approval of the general and working drawings shall not in any case relieve the contractor from any of his responsibilities under this contract.

H The said part of the first part hereby expressly agree that the inspection of materials and workmanship shall not relieve——————of any of——————obligations to perform sound and reliable work, as herein described. And the said part of the first part further agree to repair or replace any defective part or piece of the pumping engines during one year from the end of the 24 hours running test, at his own cost and expense.

And it is further agreed that during the aforesaid year, the Water Commissioner may make all necessary repairs requiring prompt attention, and that the cost of such repairs shall be borne by the contractor.

I And it is further agreed that any work not herein specified which may be fairly implied as included in this contract, of which the Water Commissioner shall judge, shall be done by the contractor without extra charge. The contractor shall also do such extra work in connection with this contract as the Water Commissioner may in writing specially direct, and the price for such extra work shall be fixed by the water commissioner, but no claim for extra work shall be allowed, unless the same was done in pursuance of a written order, as aforesaid.

J The said part of the first part further agree that the work embraced in this contract shall be begun within one week after written notice so to do shall have been given to the contractor by the Water Commissioner, and continued (unless the said commissioner shall otherwise in writing specially direct), with such force and in such manner as to secure its completion within twenty-six months thereafter, the time of beginning, rate of progress, and time of completion being essential conditions of this contract. And the part of the first part further agree that if the pumping engines to be furnished under this contract are not completed at the time above specified, then there shall be retained by said second party, as ascertained and liquidated damages, the sum of fifty ($50.00) dollars per day for every day thereafter until said engines are ready for service.

The party of the second part agrees to have the pump pits ready for the commencement of the erection of the engines within twenty months, and to have the steam ready for testing and running the engines twenty-three months after the date of the above notice to begin work. K

And the part of the first part further agree that shall not be entitled to any claim for any hindrance or delay from any cause whatever in the progress of the work, or any portion thereof; but any hindrance or delay occasioned by the party of the second part shall entitle said part of the first part to an extension of the time for completing this contract, sufficient to compensate for the detention, the same to be determined by the Water Commissioner. L

The said part of the first part further agree that will not sublet the work to be done under this contract, but will keep the same under control, and that will not assign the same by power of attorney or otherwise, and that will at all times have a representative present where any work is in progress under this contract. Whenever it may be desired to give directions, orders will be given by the Water Commissioner and obeyed by the contractor's representative who may have charge of the particular work in reference to which orders are given. If any person employed by the contractor on the work should appear to the Water Commissioner to be incompetent or disorderly, he shall, upon the requisition of the Water Commissioner, be at once discharged and not again employed. M

It is further agreed that if the part of the first part shall assign this contract, or abandon the work to be done under this agreement, or shall neglect or refuse to comply with the specifications or stipulations herein contained, the board of public improvements shall have the right, with the consent of the mayor, to annul and cancel this contract, and to relet the work or any part thereof; and such annulment shall not entitle the contractor to recover damages on account thereof; nor shall it affect the right of the City of St. Louis to recover damages which may arise from such failure. N

And the said first part hereby agree to protect and defend and save harmless the said city of St. Louis against any demand for patent fees on any patented invention, article or arrangement that may O

be used by said first part in the pumping engines furnished under this contract.

P The said part of the first part further agree to indemnify and save harmless the City of St. Louis from all suits or actions brought against the said city on account of injuries or damages received or sustained by any party or parties during the construction of the pumping engines, or by or in consequence of any negligence in guarding the same, or any improper materials used in the construction, or by or on account of any act or omission of the said part of the first part or agents.

Q The part of the first part further agree that each engine furnished under this contract shall have a pumping capacity of ten million U. S. gallons in twenty-four hours. The capacity to be at a speed that will insure smooth and quiet action, and to be determined by the experts during the duty test.

R The part of the first part hereby agrees that the pumping engines furnished under this contract shall perform, during a running test of twenty-four hours, a duty of one hundred and twenty-five million foot-pounds per thousand pounds of commercially dry steam.

The part of the first part further agree that in case either engine fails to perform a duty of one hundred and twenty-five million foot-pounds per thousand pounds of steam, during the working test of twenty-four hours, ——— will pay to the party of the second part, as an agreed measure of damages for lack of efficiency of the engine, in the ratio of $2,500.00 for each one million foot-pounds which the duty falls below one hundred and twenty-five million.

In case either engine exceeds, during the twenty-four hours working test, an average duty of one hundred and twenty-five million foot-power per thousand pounds of steam, the party of the second part agrees to pay to the part of the first part, as a reward for the superior efficiency of the engine, an amount to be in the ratio of $1,000.00 for each one million foot-pounds which the duty comes above one hundred and twenty-five million.

S On condition of the true and faithful performance of all the conditions of this agreement and specifications, the said party of the second part agrees to pay to said part of the first part the sum of ——— dollars, subject to such additions or

deductions as are authorized by the provisions and conditions of this contract, in full payment for all the work and materials, designs and drawings required by this contract, embracing the satisfactory construction and erection of such pumping engines and appurtenances as are herein defined and described in all their parts and requirements.

Payments on account will be made as follows, viz.:

a. On or about the first of each month, the Water Commissioner shall cause an approximate estimate to be made of the value of the materials and word done, based on the total amount to be paid for the engines; from the amount so found he shall deduct 20 per cent. and all sums previously paid or retained under this contract, and certify the remainder as then due. Provided, however, that nothing herein contained shall be construed to affect the right of the City of St. Louis, hereby reserved, to reject the whole or any portion of the work aforesaid, should the said certificates be found or known to be inconsistent with the terms of this agreement, or otherwise improperly given. **T**

b. When the twenty-four hours running test shall have been satisfactorily completed, the Water Commissioner shall make an estimate for the amount of the contract price, less 10 per cent., and all sums retained under this contract.

It is further agreed that the water commissioner shall have charge of and operate the engines furnished under this contract, during the twenty-four hours duty test, and the year following, and that the part of the first part shall not be relieved or released thereby from any of —— obligations under this contract.

At the end of said year, the pumping engines and appurtenances, if found to be in good working condition, shall be finally accepted, and the Water Commissioner shall make and certify a final estimate in favor of the first part and the responsibility of said first part shall then cease.

The said part of the first part further agree **U** that —— shall not be entitled to demand or receive payment for any portion of the aforesaid work or materials, except in the manner set forth in this agreement; nor until each and all of the stipulations hereinbefore mentioned are complied with, and the Water Commissioner shall have given his certificate

to that effect. The party of the second part hereby agrees and binds itself to pay the said part of the first part in cash, the whole amount of money accruing to the said part of the first part under this contract, excepting such sum or sums as may be lawfully retained under any of the provisions of this contract hereinbefore set forth, upon the giving by the said part of the first part to the party of the second part a release from all claims and demands whatsoever growing out of this agreement.

V This agreement is entered into subject to the city charter and ordinances in general, and in particular to the following provisions of Article VI., section 28, of said charter, to wit:

"*a.*" The aggregate payments under this contract shall be limited by the appropriations made therefor.

"*b.*" On ten day's notice the work, under this agreement, may, without cost or claim against the city, be suspended by the board of public improvements, with the approval of the mayor, for want of means or other substantial cause. Provided, that on the complaint of any citizen and tax payer, that any public work is being done contrary to contract, or the work or material used is imperfect or different from what was stipulated to be furnished or done, the said board shall examine into the complaint and may appoint two or more competent commissioners to examine and report on said work, and after such examination, or after considering the report of said commissioners, they shall make such order in the premises as shall be just and reasonable, and what the public interests seem to demand, and such decision shall be binding on all parties. The cost of such examination shall be borne by the contractor, if such complaint is decided to be well founded, and by the complainant if found to be groundless.

W Ordinance 16,514, approved December 22d, 1891, is hereby made part of this contract, and must be observed in all its provisions, namely:

SECTION 1. All contracts hereafter entered into wherein the City of St. Louis is a party, for the doing of any kind of work or labor for the City of St. Louis, including work on all public buildings, works and enterprises, shall contain the following terms and conditions: (*a*) That the men, persons or laborers who may be employed in the doing, prosecuting, or accomplishment of such work done

by the contractor with the City of St. Louis, or any one under him, or any person controlling the said men, persons or laborers, shall not be required to work more than eight hours a day; (*b*) That in case of the violation of such provisions of such contracts, the mayor shall immediately declare such contracts canceled and forfeited, and the work being done under such contracts shall be relet in the manner provided for the letting of such work, and such contractor shall thereafter be ineligible to bid upon such work under such reletting, and the difference in the cost of doing such work under such contract so canceled and forfeited, and under such reletting, shall be sued for on the bond of such contractor so violating such contract.

For the faithful performance of all and singular the terms and stipulations of this contract, in every particular, the said——— part of the first part, as principal, and———as securities, hereby bind themselves and their respective heirs, executors and administrators, unto the said City of St. Louis, in the penal sum of——dollars, lawful money of the United States, conditioned that in the event the said ———shall faithfully and properly perform the foregoing contract according to all the terms thereof, and shall as soon as the work contemplated by said contract is completed, pay to the proper parties all amounts due for material and labor used and employed in the performance thereof, then this obligation to be void, otherwise of full force and effect, and the same may be sued on at the instance of any material man, laboring man or mechanic, in the name of the City of St. Louis, to the use of such material man, laboring man or mechanic, for any breach of the condition hereof; provided, that no such suit shall be instituted after the expiration of ninety days from the completion of said contract.

In witness whereof, the said———part of the first part, as principal, and———securities, parties of the first part, have hereunto set their hands and seals respectively, and the City of St. Louis, party of the second part, acting by and through the board of public improvements aforesaid, have subscribed these presents the day and year first above written.

WITNESS:

———————	———————[seal]
———————	———————[seal]
	———————[seal]

The City of St. Louis by——————
President Board of Public Improvements.
Countersigned: ——————
Comptroller.

CITY COUNSELOR'S OFFICE.
St. Louis,——————18—
The foregoing Agreement and Bond are in due form according to law.

——————
City Counselor.

MAYOR'S OFFICE.
St. Louis,——————18—
I hereby approve of the Securities to the foregoing Contract and Bond.

——————
Mayor.
M. L. H.

169. Complete General Specifications for Water Tubular Boilers and Settings. The following complete general specifications for horizontal water tubular boilers were used in connection with the engine specifications given in the previous article, and the contract was let under similar contracting, general, and surety clauses. These portions are omitted from these specifications for the sake of brevity. They were prepared by the same gentleman who prepared the specifications in the last article, and are thought to represent an equally good practice.

1. The work to be done consists in furnishing designs and plans, material, tools and labor, and building, transporting and erecting complete in place, ready for firing, in the boiler-house at Bissell's Point, eight horizontal water tube boilers, the boilers to be provided with all necessary valves, gauges, breechings and connection to underground smoke flue.

DESIGN.

2. The boilers to be of the type designated as horizontal water tube boilers, designed and built with special reference to easy access for cleaning and repairing of both internal and external surfaces. The boilers to be designed for natural draft of pres-

ent smoke stack. No stays or obstructions of any kind shall be placed inside of the water tubes.

3. The boilers to be designed for a working steam pressure of 140 pounds per square inch, with a factor of safety of six on minimum sections.

4. Each boiler shall have a total tube heating surface of not less than 3,000 square feet, and a grate area equivalent to 75 square feet of straight grate.

5. The boilers to be provided with smoke preventing furnaces, which shall effectually stop smoke while burning southern Illinois coal at a rate of from twenty (20) to twenty-five (25) pounds per square foot of grate per hour. The furnace shall be some well tested and approved device for prevention of smoke, which does not use a steam jet or a system of brick arches in the fire box.

6. The boilers to be set in four independent batteries, as shown on drawing, each boiler to be provided with walls, settings, valves, gauges, smoke breeching and dampers necessary for operating or repairing independently of other boilers.

7. The fire fronts shall be designed to facilitate firing and removing ashes. The fire doors to be of suitable design to secure the regulation of air admitted to the fire, and prevent radiation through the fire door openings during regular service. The boiler dampers to be arranged to regulate from front of boiler.

8. Each boiler to have an eight-inch stop valve, Fittings
admitting of independent connection to main steam pipe.

To each boiler there shall also be attached, besides the eight-inch stop valve, two three and a half inch improved pop safety valves, placed in such positions that their escape pipes will not interfere with the roof trusses or sky-lights of the boiler house.

9. All steam drums to be made of steel plates of the quality hereinafter specified.

10. The boilers to be set and supported in a manner admitting of expansion and contraction of the same, without injury to the brick work or boilers in any way.

All beams required to support or carry the boilers to be of ample strength, and must be either wrought iron or steel.

There shall be central air spaces in all walls enclosing the boilers.

FITTINGS AND APPURTENANCES.

11. The contractor shall furnish and put in place all necessary valves, steam gauges, water glass gauges, safety valve escape pipes, and all appurtenances, and make connection to steam main, feed and blow-off pipes and underground smoke flue.

Wrenches.

12. For all nuts on the boilers and fittings, there must be furnished well-fitted wrenches.

Steam Gauges and Plugs.

13. The steam gauges shall be attached to the boiler fronts with nickel-plated brass siphon pipe and cocks, in a neat manner, admitting of easy removal.

The feed-water valve of each boiler to be provided with a suitable arrangement for its regulation from the front of the boilers.

Steam gauges to be brass case, nickel-plated, fourteen inches in diameter, maximum pressure 250 pounds, five-pound divisions.

14. Each boiler to be provided with three Bailey's safety copper cap fusible plugs, or other safety plugs of equally good manufacture and satisfactory fusibility.

Drains.

15. There shall be suitable copper spouts and polished brass piping wherever visible, to catch the steam and water from the gauge cocks and glass water gauges, and they shall be piped and connected to the ash box in an acceptable manner.

Valves.

16. Steam valves above six inches in diameter shall have steel stems, provided with phosphor bronze nuts, and the glands of all stuffing boxes shall be of composition.

17. All valves, fittings, fixtures and appurtenances used shall be of the best design.

18. The steam drums and all parts of the boilers and pipes not covered by brick work, and the breechings to be covered with magnesia covering, not less than one and a half inches in thickness, thoroughly secured in place.

19. Hand hole plates must be secured in an approved manner, to insure the greatest possible safety against accidents from breaking of fastenings.

MATERIALS.

20. All material used throughout this construction must be of the special class and grade called

for in the specifications, and shall in each case fully stand the specified tests.

21. All plates in the boilers to be made of steel. Steel Plates.

The steel plates used in these boilers must be stamped with the maker's name and the tensile strength; to be homogeneous and of uniform quality, to have a tensile strength of not less than 55,000 pounds, nor more than 62,000 pounds per square inch, an elastic limit of at least 30,000 pounds per square inch, and an elongation of at least twenty-four (24) per cent. in eight inches.

Specimens must stand the following bending test, viz.:

To bend double, closing up completely without showing sign of fracture when bent cold, or after having been heated to a cherry red and plunged into water at 70 degrees Fahrenheit.

The water commissioner shall have the right to order test specimens 2x14 inches, to be cut out of any of the plates to be used in the boilers.

22. All wrought iron for bolts, nuts or other purposes shall be double refined, and have an ultimate tensile strength of at least 52,000 pounds per square inch, an elastic limit of 26,000 pounds per square inch, and an elongation of eighteen (18) per cent. in eight inches. Wrought Iron.

23. Rivets to be Burden's best, and must be capable of bending cold until the sides are in close contact, without sign of fracture; and iron used for screw stays, stay bolts and braces to be of best quality of American manufacture.

24. Tubes to be lap-welded of the best quality of American manufacture, of a diameter of 3½ inches or 4 inches, and must stand a satisfactory hammer test. Tubes.

25. All castings shall be free from blow holes, flaws, scabs, and defects of any description, and shall be smooth, close-grained, sound, tough, and of true forms and dimensions. Castings.

Great care must be taken to make all castings, as nearly as practicable, of uniform thickness throughout, when not otherwise required.

26. All cast iron used under steam pressure shall be of good quality, tough and of even grain, and shall possess a tensile strength of not less than 22,000 pounds per square inch. Iron Castings.

Test bars of the metal, two inches by one inch, when broken transversely, twenty-four inches between supports and loaded in the center, shall have a breaking load of not less than 2,200 pounds, and shall have a total deflection of not less than $\frac{35}{100}$ of an inch before breaking.

The test bars shall be cast as nearly as possible to the above dimensions, without finishing, but corrections will be made by the water commissioner for variations in thickness and width, and the corrected results must conform to the above requirements.

27. If any two test bars, cast the same day, show a tensile strength less than is required in these specifications, or do not show the required cross breaking load or deflection, all castings made from the melting from which the samples were taken may be rejected.

Specimens. 28. Test specimens and samples of castings and forgings, or any other kind of material used in this construction, shall be prepared ready for testing and supplied in the number, shape, finish and sizes required by the water commissioner, and shall be prepared as may be directed at any time during the pouring or working of materials.

29. The stamps put upon the steel sheets by the manufacturer must at all times be preserved for identification, and so placed as to be visible on the outside of boilers; if any stamp is cut out in process of manufacture, the water commissioner shall first replace it by a duplicate stamp.

WORKMANSHIP.

30. The best workmanship on these boilers will be exacted, and it must be equal in all respects to that executed in the best boiler works in this country.

31. All holes for bolts, studs and rivets in castings must be drilled. No cored bolt holes will be allowed.

No plugging or other stopping of holes or defects of castings will be allowed.

32. Any rivet which is deformed, cracked, burnt, improperly driven, leaky, or in any way injured, must be cut out and properly replaced.

33. All surfaces of sheets, and other parts to be riveted, must be brought together to close contact and accurately fitted, with bearing surfaces

smooth and clean, and while being riveted to be held firmly in position and alignment without exerting injurious strains upon any portion or detail of the boiler.

34. The use of drift pens, to bring rivet holes to match, or come true and central, will not be allowed in the process of riveting, and must be dispensed with entirely. The utmost accuracy in punching the rivet holes will be exacted. Rivet holes failing to fit, or come fair and true, must be reamed out accurately, and rivets of suitable size used.

35. All sheets of the boilers must be satisfactorily straightened before being planed, bent, flanged, drilled, fitted, etc. Sheets.

36. All scarfing to be done in a neat and workmanlike manner. Sufficient allowance of material must be made at all places where scarfs are required.

37. The edges of all sheets to be planed to a suitable bevel.

38. All seams to be caulked on both sides where accessible. Caulking.

All caulking to be done in the best manner, with round-nosed caulking tools; great care to be taken not to mar the sheet or rivets.

39. The threads of all studs, bolts, screw stays, stay bolts and nuts, to be chased with great care and skill, to insure uniformity in pitch and accuracy in fit. Threads.

All holes which are to receive bolts, screw stays, studs or stay bolts, to be accurately centered, drilled and tapped, to give a desirable fit and tightness of the threads.

The stay bolts, screw stays and studs to be entered, screwed in and riveted in a careful and workmanlike manner, to insure true and parallel surfaces and an equitable distribution of the stress upon all of the sustaining members.

40. All expanding of tubes and nipples shall be done in a careful and workmanlike manner, and shall be absolutely water-tight under the test pressure.

41. The fire, ash and cleaning doors to be fitted air-tight to their seating or bearing surfaces. Doors.

All holes in the lugs for hinges of the doors used in the construction to be drilled and reamed, to accurately fit the turned pins for same.

42. The brick work must be executed in a thorough and workmanlike manner, the brick used to be strictly first-class in every respect. Outside of setting to be laid with stock brick in white mortar; inside, where exposed to heat, to be lined with best quality fire brick.

43. All red bricks to be laid in mortar of approved quality, and all fire brick to be laid in ground fire clay.

FOUNDATIONS.

Foundations. 44. The city will furnish complete foundations for the boilers, the position in the house to be as shown on plans on file in the office of the water commissioner, and the space occupied by each battery of boilers to be not greater than that shown.

GENERAL CLAUSES.

Pressure Test. 45. The boilers shall be tested by the contractor with a water pressure of 210 pounds per square inch, under which they must be water-tight.

Paint. 46. When the boilers shall have been tested to the satisfaction of the water commissioner, they shall be thoroughly scraped, cleaned, dried and painted outside with one coat of linseed oil.

47. The fire front, fire and ash doors, and other cast and sheet iron parts, except grate bars, after approval shall be painted in the shop with one coat of paraffine varnish, and after erection they shall receive another coat of the same.

Erection. 48. The contractor shall, at his own expense and risk, transport the boilers and appurtenances to Bissell's Point, furnish all necessary labor, tools and appliances, and erect the same complete, as above specified.

Every possible and necessary care must be taken in handling and transporting the boilers, to prevent injury of any description to the same.

49. The contractor shall so conduct his work as not to interfere with the operation of any boilers under fire, and the disposal of his tools and materials, during storage and erection, will be subject to the approval of the water commissioner.

50. The contractor shall, at his own cost, make good all damages to masonry, buildings or other property of the city of St. Louis, occasioned by the contractor or his employees in the transportation and erection of the machinery.

51. The city of St. Louis will furnish space within its premises for the reception of the boilers and details, but shall not be responsible for the safe keeping of the same, nor for damage caused to them from exposure or other causes. Storage.

52. The city will remove the old boilers and prepare foundations below the floor line for new boilers, contractors to furnish castings to be set in underground flue for smoke connections.

53. The contractor shall get all finished materials on the ground at the earliest possible moment, and proceed with the erection of the same as soon as notified by the water commissioner.

The work of erection in place, ready for firing, shall be carried on continuously, night and day, and the contractor shall provide for that purpose three complete erecting gangs.

If at any time during the erection the water commissioner shall be of the opinion that the work can be expedited by the employment of additional labor or tools, he shall order the contractor to make such increase in his working force or appliances as he may deem necessary to secure the most rapid progress possible; and it is especially understood and agreed that if the contractor fails to put the required force at work promptly, that the water commissioner shall employ such labor as he may deem necessary, and charge the cost of the same to the contractor.

54. The contractor shall bear the cost of making all repairs necessitated by defective materials, workmanship or design of the boilers and furnaces for the space of one year after the boilers are put into regular operation. M. L. H.

170. Specifications for an Engine House. The following specifications for an engine house differ from those in the two previous articles inasmuch as they were accompanied by complete detail drawings. The contracting and surety clauses are here omitted, since they would be the same as those given in article 168. This engine house covers three large pump pits, designed for three sets of low service pumping engines, and it is entirely without a floor, nearly the entire space being occupied by the pits. The walls rest directly upon the natural rock, and an electric traveling crane is carried by a track near

the top of the two side walls, this crane spanning the entire opening and running the entire length of the building. The side walls, therefore, were made very strong and substantial.

Work to be done. 1. The work to be done consists in building and finishing complete Low Service Engine House at Chain of Rocks, St. Louis City Water Works Extension. The foundation on which the structure will rest is now completed. The work is shown in detail on the following drawings:

No. 1. Elevation of side walls.
" 2. " end walls.
" 3. Longitudinal section.
" 4. Transverse sections.
" 5. Plan below traveler.
" 6. " above "
" 7. Gallery plan.
" 8. Roof plan.
" 9. Roof plan for iron trusses.
" 10. Cut stone courses.
" 11. Details of stone faced door and window openings, terra cotta details.
" 12. Details of cut stone in cornice, fire walls and brick arches.
" 13. Details of windows, doors, ceiling and cast iron door sill.
" 14. Details of large sliding doors and hangers.
" 15. Details of door and window frames.
" 16. Details of sky lights.
" 17. Details of galleries, stairs, ladders, balcony and door sills.
" 18. Details of iron trusses.
" 19. Strain sheet.
" 20. Details of brick cornice, fire walls, etc.

MORTAR.

Sand. 2. All sand for mortar shall be clean, sharp, coarse, Mississippi river channel sand.

Cement. 3. All cement used in the masonry shall be H. H. Meier's Puzzolan cement, put up in well-made barrels.

4. It shall be subject to such tests as may be necessary to fully determine its character, and any cement which, in the opinion of the water commissioner, is unfit for the work herein specified will be rejected.

5. All short weight or damaged barrels of cement, or cement without the maker's brand, will be rejected without test. Samples for testing shall be furnished at such times and in such manner as may be required. On all barrels accepted inspection marks will be placed, and the contractor shall care-

fully preserve these marks and not allow them to be imitated.

6. All cement for use on the works shall be kept under cover, thoroughly protected from moisture, raised from the ground—by blocking or otherwise—and dry until used. The contractor shall keep in storage a quantity of accepted cement sufficient to insure the uninterrupted progress of the work.

7. Cement may be reinspected at any time, and, if found to be damaged or of improper quality, will be rejected. All rejected cement shall at once be removed from the line of work.

8. All mortar used in the masonry shall be cement mortar, and shall be made of three parts of sand and one part of cement, each of the quality above specified. All mortar shall be made fresh for the work in hand, and any mortar which has begun to set shall not be used. **Mortar.**

9. All brick in outer face of walls shall be laid in mortar, colored with a red mortar stain that is even in color and durable, and approved by the water commissioner. **Colored Mortar.**

STONE MASONRY.

10. The base, ashler and water table courses shall be of Missouri red granite, sound, free from discolorations, and of even color. All visible rock face shall be free from drill-holes or tool-marks. Base course and water table shall be six-cut work, ashler course, rock face. **Granite.**

11. Base course shall be 12 inches high, 8½-inch bond, with 4-inch by 4-inch chamfer on top. Ashler course shall be 1 foot 4½ inches high, 13-inch bond on the setting bed and 8½ inch bond on the top bed, and cut for iron anchors. Water table shall be 7½ inches high, 6-inch bond, cut for iron anchors and chamfered on top as shown. The ashler and water table course shall be anchored to the brick backing with tarred wrought iron anchors.

12. All of the granite work shall be laid in the most workmanlike and substantial manner, with even and equal joints, ¼ inch thick. Each stone must have perfect and level beds. All joints shall be pointed well and neatly with pointing mortar, colored red. Pointing joints must show equal size throughout, and be struck with pointing tool and straight edge.

13. Eight stones, 2 feet 0 inches by 15 inches by 18 inches, and ten stones, 2 feet 0 inches by 14 inches by 15 inches, shall be furnished and set as directed, to be used as bed stones for roof trusses; said stones shall be of granite, sound in all respects, top and bottom beds dressed true and level.

Sandstone. 14. Window sills, sill courses, belt course, coping, pediments, range work around door and window openings, and all cut stone work above the water table, shall be of Lake Superior red sandstone; fine Crandall finish, laid with equal and even ¼-inch joints in full beds of mortar. All joints shall be without chipping and beds of stone level and perfect. Spalls shall not be used in leveling any portion of the work. Window sills shall be cut with drips and seats, the seats not being cut to exact size until after the frames are set.

15. All the sand stone work shall be cut and set in the very best manner, and the whole cleaned down perfectly, and pointed with red pointing mortar, with concave joints, and backed up as soon as set.

16. The stone must be perfect in all respects, even color, free from all defects or pockets.

17. In cleaning down the work, care must be taken that the joints are rubbed to a level surface.

Limestone. 18. The stone bed course for the track of the crane shall be made of lime stone from approved quarries, dressed smooth on top bed, bush-hammered on face, and with true and parallel beds. This course shall extend the entire length of the building on each side, and it shall be 14 inches wide and 8 inches high, set in a swimming bed of cement mortar. When set same must be leveled *perfectly*, the entire length of the building, taking each side out of wind with the other. Special care must be exercised in cutting and setting this course. See detail sheet No. 20.

BRICK WORK.

Brick. 19. All the exterior faces of the walls, jambs, etc., shall be executed with even-colored dark red and hard brick. All other portions of the brick work executed with strictly red and hard quality. Light red brick shall not be used in any portion of the building, nor will salmon or defective brick be allowed in *any* part of the walls or on the premises.

20. Brick in exterior of walls shall be laid in red mortar, with even and full bed and end joints, struck with a concave tool, as the work progresses. **Face.**

21. The standard height for laying all brick shall be 2 courses to 5 inches, unless otherwise ordered by the water commissioner. **Height of Courses.**

22. Figured thickness of walls will govern. **Thickness of Walls.**

23. The brick in every fifth course shall be headers, and face work shall be laid to bond with Flemish bond headers, as directed by the water commissioner, during the progress of the work. **Bond.**

The different courses shall be slushed, and all joints thoroughly filled with cement mortar.

All courses shall be laid to a line, front and rear; plumb, true, straight and level.

24. All arches shall be turned with arch-brick, ground to proper radiating lines, and the face of same shall be laid, alternately, 8½ inches and 4½ inches, and backed up with row locks laid with shove joint. All jambs shall be returned and neatly pointed. All arches shall be full depth of wall. Turn brick arches over seats of each truss, as shown on sheet No. 18. **Brick Arches**

25. Brick must be thoroughly wet before laying, if required. Stone walls shall be well swept off and sprinkled with water before any brick is laid on them. **How Laid.**

26. Cut a sufficient number of recesses through the stone foundation walls for passage through same of the copper down-spouts, and build them in with stone work, as shown on sheet No. 1. **Notches in Foundation**

27. All frames, anchors, wood, bricks, etc., that are necessary shall be built in. **Setting Cut Stone above Water Table**

28. All cut stone above the water table shall be set, and the walls carefully leveled for the reception of the iron trusses. After the walls are built all sills shall be under-pinned with red mortar.

29. All necessary wood plates for the fastening of tin flashing shall be built in.

30. All terra cotta shall be bonded firmly to the brick work and neatly pointed with red mortar at completion. **Setting Terra Cotta**

31. Two iron I beams shall be built in and covered with a ⅜-inch plate, where shown on sheet No. 3, in the side wall over the traveler off-set and above the circle head windows, leaving the wall open on the under side, so that the traveler can be carried through this opening. After traveler has been set **Iron I Beams**

in position the opening shall be closed up with brick work, leaving the I beams in the walls, but not exposed.

Cleaning Down. 32. All exterior brick walls shall be cleaned of all dirt and mortar stains at completion.

TERRA COTTA.

Quality. 33. All the terra cotta letters and border around same, on east and west walls, to be hard burned, best quality red, even in color, and of designs and dimensions shown, free from "flashing" or warping.

Moulds. 34. The letters shall be first modeled and a plaster mould made, and from the mould the letters shall be pressed.

Fitting. 35. After terra cotta has been burned it shall be laid out and carefully fitted and shaded and trimmed if necessary, after which each piece shall be lettered to correspond with a setting plan which shall accompany the delivery of all terra cotta. The details for the terra cotta will be found on sheet No. 11.

How Set. 36. All terra cotta to be set in putty, colored to match, and properly bonded to the brick backing. The bricklayers shall set all terra cotta.

COPPER WORK.

Down-Spouts. 37. Four 10-inch square down-pipes, 16-ounce copper, to lead water from roof and connect same with sewer, shall be furnished in place. Each down-pipe shall have square copper head of 20-ounce copper, and moulded copper bands of double thickness of 16-ounce copper placed not more than 4 feet apart, and secured with 3-inch copper holdfasts, with rosette heads.

Gutters, etc. 38. Gutters shall be formed with roofing tin of form and size shown on drawings for same, and constitute a part of the roof-covering, and graded so as to carry the water from the center to the four corners of the building and open into the copper down-spouts. Tin gutters shall be carefully flashed and counterflashed into the brick fire-walls, and nailed to wood strips provided for said flashing, as provided for in clause No. 44.

Finials. 39. The copper finials for the skylights shall be furnished and secured in place.

40. Copper drip strips, $1\frac{3}{4}$ inches wide, 1 inch to project into the mortar joint, and $\frac{3}{4}$ inch to be exposed and bent to an angle of 30°, as shown on detail sheet No. 12, shall be furnished the bricklayers on the scaffold. Drip.

TIN.

41. The roof shall be covered with roofing plates, standing seam, with joints well tacked, anchored and soldered, using rosin as a flux, and 8-pound soldering coppers, and tin well and closely cleated to roof.

42. The roofing plate used shall be Scott's IX extra coated American roofing tin plate, and must bear a coating of not less than 36 pounds to the box, and must be fully guaranteed, with the maker's name stamped in each sheet, and each sheet must be coated in perfect uniformity and free from "wasters." Tin Plate.

43. The gutters shall be lined with Scott's IX roofing tin, flat seam, and shall conform to the gutter plan as shown on sheet No. 8, and shall be carefully flashed against the brick fire-walls, and be firmly nailed to the wood flashing strips, after which all of this gutter flashing must be well and carefully counterflashed. Gutters and Flashing.

44. The wood flashing strips shall be built into the brick fire-walls 8 inches above the wall edge of gutter at center of roof and 24 inches above at each of the four corners.

45. The flashing around the skylights shall extend against and 8 inches up the wood skylight frame, and shall be finished before the carpenter lays the base. Skylight Flashing.

46. Tin shall be painted, before being laid, with two coats of the best quality of iron oxide, ground in pure linseed oil, on the under side, and must be perfectly dry before laying; and that part of the roof covered with tin shall have two layers of heavy straw building paper laid over sheathing boards before putting down the said tin. Each layer of paper to overlap and be fastened down smooth and flat, and to be kept free from moisture. (See clause No. 51.) Paint and Paper.

LUMBER.

47. All the lumber used in the construction of the building shall be graded as follows:

Carpenter Work.

Purlins—4-inch by 10-inch, yellow pine, long leaf, surfaced three sides and stub moulded.

Lower Roof Sheathing—1½ inches by 4 inches, tongued, grooved and beaded on under side, "B" select, surfaced one side.

Upper Roof Sheathing—⅞ inch by 8 to 10 or 12 inches No. 1 ship lap, surfaced one side.

Skylight Frame—Posts and plates, 5½ in. x 5½ in. yellow pine No. 1.
" " Rafters, 4 in. x 4 in. yellow pine No. 1.
" " Nailing girths, 2 in. x 6 in. white pine No. 1.
" " Outside casing, ⅞ in. "B" select.
" " " base, 1½ in. "B" select.
" " Inside casing, ⅞ in. "B" select.
" " " lining, ⅞ in. x 4 in. beaded white pine, "C" select.
" " Plinth and base blocks, 1½ in. "B" select.

Flashing strips—2 in. x 4 in., No. 1 white pine.

1st gallery floor girders.—3 in. x 8 in. and 2 in. x 6 in. No. 1 long California yellow pine, surfaced three sides.

1st gallery floor.—1½ in. x 3 in., first and second yellow pine, tongued and grooved.*

Mill Work.

Tread board—2 in. x 12 in. white oak.
Window frames—"B" select.
Sash—"A" select.
Doors—"B" select.

Quality.

48. All lumber must stand *strictly* on grade, kiln dried, free from large loose knots, sap, shakes, rot, stain or any other defects foreign to their respective grades.

CARPENTER WORK.

Roof.

49. The roof shall be covered with two courses of sheathing. The lower sheathing shall be white pine, tongued, grooved and beaded, and shall be 1½ inches thick by 4 inches wide; under side dressed and smoothed at the bench to a perfect smooth surface, and fastened to place and left free from hammer-marks or other defects. Upper sheathing shall be ⅞ inch by 8, 10 or 12 inches wide, No. 1 ship lap, laid diagonally, and nailed to the lower sheathing. Care must be taken that nails shall not go through the lower sheathing; the nailing to be in the purlins.

50. All purlins shall be 4 inch by 10 inch long leaf yellow pine, surfaced three sides, stub moulded, dry, sound and straight grained. They shall be spaced on centers, as shown on detail sheets Nos. 18 and 9, and secured to upper cord of truss by angles and bolts, as detailed.

* There is no floor proper in the building, only a narrow gallery around the sides.
AUTHOR.

51. Cover the entire roof with two (2) layers of heavy straw building paper, laid over the ship lap sheathing before putting down the tin. Each layer of paper to overlap and be fastened down smooth and flat, and to be kept free from moisture. This work shall be performed by the carpenter, under the direction of the tinner, and laid in such sections only as required to keep in advance of the tinners. The upper sheathing, paper and tin shall be laid as fast as the lower sheathing is nailed in place, so as to protect the ceiling at all times from the weather.

52. Skylights shall be three (3) in number, and framed in accordance with details for same, as shown on sheet No. 16 (this sheet shows details for the two end lights only; the center light shall be of same construction, but of sufficient length to reach the distance of two truss centers, as per longitudinal elevation and roof plan). The principal posts shall be of 5½ inch by 5½ inch yellow pine, and shall be fastened to purlins with wrought iron anchor straps firmly bolted to both purlins and posts. The upper end of all posts shall be tenoned. **Skylights.**

53. Wall plates shall be 5½ inch by 5½ inch yellow pine, and mortised to fit the post tenons, and all fastened together with strap iron anchors and bolts.

54. The hip rafters shall be made of 4 inch by 4 inch yellow pine and dressed four (4) sides, and shall be backed same as for wood sheathing, and upon the top of plates between heels of rafters spike a triangular strip of wood secured rigidly to the plate to receive the thrust of the skylight bars. The center cage shall have the necessary rafters shown on sheet No. 8, and be firmly bolted at apex through a ridge piece of 2 inch yellow pine, top edge of ridge beveled.

55. Nailing girths shall be 2 inch by 6 inch white pine, No. 1, and be firmly spiked to the framing.

56. The outside shall be cased up with ⅞ inch "B" select, to form the finish above the base. A baseboard of 1½ inches thick, "B" select, beveled on top edge, shall run around the entire frame and be firmly nailed to the casing. See clause No. 45.

57. The inside shall be trimmed by casing up the posts with ⅞ inch thick "B" select, fluted and nailing on plinth and base blocks as shown. The inside below the window stool shall be ceiled with

⅞ inch x 4 inch beaded "B" ceiling, nailed on diagonally, with the nails countersunk and finished at the bottom with a 2-inch band mould.

58. (For specifications of skylight roof, see clause No. 112.)

Ceiling 59. The roof ceiling shall be finished by running a mould along the truss and purlins, forming the different panels, as per detail sheet No. 13.

Gallery Floor. 60. The floor of lower gallery shall be made of 1½ inch by 3 inch tongued and grooved first and second yellow pine in continuous lengths. It shall be blind nailed to girders and the nailing joist.

61. The nailing joist shall be 2 inch by 6 inch No. 1 long leaf yellow pine, and in continuous lengths from bracket to bracket and bolted to channel bar.

62. The floor girders shall be 3 inch by 8 inch No. 1 long leaf yellow pine, surfaced three sides, notched on brackets. All joints shall rest on brackets.

Centers, Templets, etc. 63. The carpenters shall furnish all centers and templets, and shall put up and take down same. The centers and templets shall be made in a proper manner, strong and well braced.

Frames. 64. The carpenter shall set all frames, and verify their plumb after the brick arches are turned.

MILL WORK.

Window Frames. 65. Window frames below the traveler shall be solid frames for top and bottom pivoted sash, and shall be made of form and dimensions called for by the drawings. The lumber used in their construction shall be clear, dry, and sound Wisconsin white pine, "B" select, free from knots or sap. Faces of all frames shall be moulded as per detail.

66. All frames shall be given a heavy coat of paint all around, including back of jambs, and shall be set perfectly plumb; and the sill shall rest on a bed of cement mortar, ¼ inch higher on the inside, so as to make a water tight joint. Casings, mullions, transoms, etc., shall be moulded as shown on details. The frames shall be put together in a strong manner, well and closely nailed, and the stop-beads fastened with 1½-inch blued round-headed screws. All the lumber in frames shall be Wisconsin white pine, "B" select, as above specified.

67. The frames shall be provided with moulded stool, terminating with mould against plaster. Mullions and jambs shall be cut down square on stone seats.

68. Stiles, heads, mullions and transoms shall be solid. All circular portions of frames shall be worked in the solid and put together with white lead, so as to break joints throughout, and firmly spiked. A 2 inch by 4 inch bond strip shall be spiked to all frames (except the two door and the two large window frames), extending from sill to spring of arch for anchoring same to brick backing. The heads of frames shall have wood blocks of 2 inch by 4 inch by 8 inche nailed to same and spaced a distance of 18 inches on centers.

69. The two door and window frames above mentioned shall be anchored to the brick backing with wood blocks of bone dry white pine 4 inch by 12 inch by 12 inch, built in the brick work, and spaced as shown on detail sheet No. 11. The frames shall be bolted to same with ¾ inch by 8 inch lag screws. The frames shall fit in a recess of one inch in the brick work.

70. Inside mould and stools will not be nailed in place until plastering is perfectly dry.

71. Two iron dowels shall be placed in the bottom of each jamb and mullion. The dowels shall be of 1-inch round wrought iron, and sunk 1½ inches in stone sill.

72. All frames above the traveler shall be solid frames for side pivoted sash and for 13-inch walls, and shall be made of "B" select.

73. All window sashes shall be of the form and dimensions called for by the drawings. The lumber used in their construction shall be clear, dry and sound Wisconsin white pine ("A" select), free from knots or sap. **Sash.**

74. All sash shall be moulded and rebated 2¼ inches thick, and divided into lights as shown. Each sash shall be neatly fitted and properly hung with Wollensak's plain bronze sash centers, No. 144, and shall be secured with bronze cupboard turns, and provided with casement rods or shutter holders. No. 8020, p. 1876, "Simmons."

75. All transom sash that are fixed shall be closely fitted and secured in place with heavy coat of white lead in the stop joints, so that all joints shall be water tight.

76. Skylight sash shall be 2¼ inches thick, and divided as shown on sheet No. 16, center pivoted and made water tight.

Door Frames. 77. The door frames at each end of the building shall have rebated solid plank frames, beaded and moulded on outer face to match window frames. They shall be built in same manner as specified for window frames, using "B" select, and shall be secured to brick work in the same manner as specified for other frames. The frame for the double door, south end, shall be rebated for 2¾ inch doors, and shall have a transom bar 3⅞ inches thick. The single door at north end shall be made without transoms and shall have 1¾ inch rebate.

Doors. 78. The doors at the south end shall be double, and each door shall be hung with four 6 inch by 6 inch real bronze butts, rebated at center joint and beaded.

79. The doors shall be 2¾ inches thick and made of dry "B" select, with stationary sash divided in lights as shown; lower portions of the doors shall be paneled and moulded as shown by detail sheet No. 13; the panels shall be made of tongued and grooved ⅞ inch "B" select, 2 inches wide, with all joints beaded and driven up in white lead.

80. The single door in the north end shall be made of "B" select, 1¾ inches thick. It shall have stationary sash panels, and be built as specified for south door.

81. Doors shall be secured with mortise locks, rebated for double doors, bronze knobs, plates and trimmings, and flush spring bolts, top and bottom of real bronze.

82. The sash in all doors and transoms for same shall be as specified for the window sash, and the transom sash pivoted and hung with the same kind and quality of hardware.

83. The large sliding doors shall be made of the same quality of lumber as specified for the small doors, and in two thicknesses of 1⅞ inches each, making a total of 3¾ inches, framed separately, and put together with white lead, and firmly screwed up with 3 inch screws, countersunk; they shall have tenoned stiles, rails and muntins; all tenons shall be double pinned with ½ inch white oak pins, and all shall be bolted together with iron rods, as shown by dot lines on detail sheet No. 14. The panels shall

be made of tongued and grooved "B" select, 2 inches wide and beaded both sides.

84. Small swing doors shall be framed into each large door, making four in all. They shall be hung with three (3) 4 inch by 4 inch real bronze butts, and fitted with Yale mortise locks, with keys to pass.

85. Each pair of the large sliding doors shall have wrought iron drop bars, made of 2 inch x 3/4 inch iron, bolted at one end and made to drop into a hook at the other; with a turned iron hand lift as shown on detail sheet No. 14.

86. An oak brace frame for each door opening, having form, size and radius as shown on detail sheet No. 14, rounded on each edge, shall be secured to the brick work with expansion bolts, in the most substantial manner, and framed into a girder made of 1 3/4 inch by 7 1/2 inch oak, of length equal to the run of both doors, and firmly bolted to the wall with bracketed bolts, as detailed. All to be put in position before plastering, in the most careful and substantial manner. **Oak Brace Frame for Large Doors.**

HARDWARE.

87. The numbers and pages given for hardware refer to Simmons' Catalogue. **Windows.**

88. All pivoted windows shall be hung with Wollensak's plain bronze sash centers, No. 144, and secured with plain bronze cupboard turns, No. 8535, page 1650, and real bronze casement stays, No. 8020, page 1876. Pivoted transoms shall be fitted with similar sash centers, and with Payson's solid grip transom lifts, real bronze, 1/2 inch by 6 feet, No. 0336.

89. All doors, except large sliding doors, shall be hung with butts, and fitted with Yale mortise locks and keys to pass, and top and bottom bolts for the double doors. **Doors.**

90. The two double doors in south end shall each be hung with four 6-inch by 6-inch real bronze butts, and fitted with rebated mortise Yale lock, plain bronze, for 2 3/4 inch door, with keys to pass, and real bronze extension flush bolts, plain, same as Yale pattern No. 788E., B. 34, page 1675.

91. The single door in north end shall be hung with four 6-inch by 6-inch real plain bronze butts, and fitted with lock for 1 3/4 inch door of same kind as specified for double door.

92. The four small swing doors that are built in the large sliding doors shall each be hung with three (3) 4 inch by 4 inch real plain bronze butts, and fitted with lock as specified for the north door.

Finish. 93. The finish of all hardware shall be real plain bronze throughout, and all locks shall be Yale, with keys to pass.

Iron Work for Sliding Doors. 94. Construct for the two sets of large sliding doors a hanger and track as per detail sheet No. 14. The hanger shall be made of wrought iron 11 inches wide and ¼ inch thick, bent to correspond with profile shown, and fitted with a steel track-wheel, turned with a groove, and necessary bearings. The hanger shall be firmly bolted to the doors with heavy screw-bolts, as shown.

95. The track for above hanger shall be made of steel Z bars, 4.72 pounds per foot (Carnegie catalogue No. 295), with the short flange ground to fit groove in wheel, and the large flange firmly bolted to oak girder. The track shall be equal to the run of both doors. These doors must be made to run easy and work perfectly.

PLASTER.

96. The side and end walls from the stone foundation to the top of the brick walls in the inside of the building, including window-jambs and stools, shall be plastered with Acme plaster, and given a granulated finish with white sand, applied according to the directions of agent. All walls shall have straight, true surfaces, angles plumb, jambs and stools plastered. Walls shall be laid off to represent stone courses, as directed. Joints shall be marked off when plaster is green, and shall be ¼ inch throughout, and cut with clean edges, the joints to continue around window-jambs and to be struck to represent arch stones over openings.

97. A plaster base and wainscot moulding shall be made around the building of height shown, base 12 inches by 1 inch, chamfered on top; wainscot cap, 5 inches by 1 inch, moulded and chamfered top and bottom, as shown on sheets Nos. 3 and 4.

PAINTING AND GLAZING.

98. The contractor shall furnish all material and perform all labor necessary for the proper painting of the building. All sap, knots, etc., of the wood-work shall be covered with a good coat of strong shellac before priming.

99. All wood-work to be painted shall be ied with French ochre and boiled linseed oil, all iron-work shall be primed with oxide of iron boiled linseed oil. All holes and cracks in the l-work shall be puttied and stopped on the ing coat, and again before applying the last ning coat. Priming.

100. All outside wood-work, usually painted, have four (4) coats of pure white lead, ground iseed oil, and mixed with pure boiled linseed The exterior of all frames, doors, sashes, sky-s, etc., shall have the last two (2) coats in s, as directed by the water commissioner. Outside Wood-work.

101. All tin and galvanized iron shall have, completion, three (3) coats of Dixon's Silica hite paint, thinned with pure boiled linseed oil; coat shall be allowed to dry thoroughly before ext is applied. Each coat of paint on the tin must be of a different shade, and each shade be approved by the water commissioner. Tin and Galvanized Iron.

102. All of the inside wood-work, including doors and frames, etc., shall be painted four coats of pure white lead, ground in oil, and l with pure boiled linseed oil, brushed on th and even, and grained a perfect oak on the oat, after which it shall receive a heavy coat of varnish, evenly flowed on and left in the Inside Wood work.

03. The ceiling, including purlins, skylights, shall be painted with four (4) coats of paint of y specified above, and of such colors as the commissioner may direct, and each suc-ig coat must be of a different shade, as per ion of the water commissioner. Ceiling.

04. The first gallery floor shall receive four oats of pure boiled linseed oil, and the floor s shall be painted to match the iron channel id brackets. Wood Floor.

05. All iron and steel work before leaving op shall be thoroughly cleaned from all loose and rust, and after inspection be given one priming coating of pure, raw linseed oil and iron well worked into all joints and open spaces. Iron Work.

06. In riveted work the surfaces coming in t shall be painted before being riveted together. ns of bed-plates, bearing-plates, and any parts are not accessible for painting after erection, ave two coats of paint.

107. After the structure is erected the iron work, both wrought and cast, shall be thoroughly and evenly painted with three additional coats of paint, of quality specified for the wood-work, mixed with strictly pure linseed oil, and each succeeding coat shall be of a different shade, and each shade must be determined and approved by the water commissioner.

Workmanship. 108. The painter must see that all wood-work is perfectly clean before priming or painting, and putty up all nail heads and other defects, and sand-paper smooth and perfectly prepare all wood before applying a second coat. The whole of the painting work throughout to be done in the best and most workmanlike manner, and all paint and varnish spots must be cleaned off the glass, walls and galleries at the completion of the work, and all left clean and perfect, without exception.

109. All paint must be mixed at the building, and under the direction of the water commissioner, except the priming for the iron work.

Glazing. 110. All of the glass throughout shall be American, double thick, perfectly free from any blemish, flaw or defect. All shall be set in oil putty, carefully tacked with tin glazing tacks, and back puttied.

111. All glass to be cleaned after glazing, and again after painting sash.

SKYLIGHT ROOFS.

Manufacture. 112. The skylight roofs used on this building shall be of the Vaile & Young patent, and shall be adapted to the wood cage construction, as detailed on sheet No. 16.

Bars. 113. The bars shall be of galvanized iron, except the parts exposed to the weather, which shall be of 20-ounce copper, and the said bars must be rigid enough to support the glass without deflection. The apex shall not be finished to a point, but shall be fitted to the square of the size of the copper finial, and said finial shall fit over the apex and cover all joints. This finial shall be made of 18-ounce copper and furnished with the skylights.

114. All bars not resting on rafters shall be wrought iron, encased with galvanized iron.

Gutters. 115. All skylights shall have hanging gutters of 20-ounce copper, with a fall to one corner, and

from this corner the water shall be conveyed to the main roof by means of a copper down-spout, which shall be furnished with the skylight.

116. All glass used in the skylights shall be ⅜ inch thick and ribbed. It shall be furnished by the manufacturers of the skylights, and it shall be set with special care, and under rigid inspection, and shall be of a continuous length. Glass

ROOF TRUSSES.

117. The castings shall be made from a superior quality of iron, tough and of even grain, and must conform in shape and dimensions to the drawings. Castings must be clean and perfect, without flaw or sand holes or defects of any kind. Cast I

118. With the exception of the bearing plates, the roof trussing shall be of soft steel throughout. Soft S

119. The steel must be uniform in character. The finished parts must be free from cracks on the faces or corners, and have a clean, smooth finish. No work shall be put upon any steel at or near the blue temperature, or between that of boiling water and of ignition of hardwood saw-dust.

120. All tests shall be made by samples cut from the finished material after rolling. All broken samples must show uniform fine grain fractures of a blue, steel grey color, entirely free from a fiery luster or blackish cast. Soft steel shall have an ultimate strength of 54,000 to 62,000 pounds per square inch; an elastic limit not less than 30,000 pounds per square inch, and a minimum elongation of 25 per cent. in 8 inches.

Before or after heating to a light yellow heat and quenching in cold water, this steel must stand bending 180 degrees to a curve, whose inner radius is equal to the thickness of the sample, without sign of fracture.

121. Specimen pieces of a size and form suitable for the testing machine shall be cut from any plate, angle or bar, when directed by the water commissioner.

122. If any specimen shall not conform to above requirements, all the material of the same form and manufacture as the piece from which this specimen was taken will be rejected.

123. All rivets shall be made of soft steel, and the steel for rivets must, under the above bending

test, stand closing solidly together without sign of fracture.

Specimen Bars. 124. For all material taken by the water commissioner for testing there will be added to the final estimate the following prices, viz.:

For all steel, the sum of five cents per pound.

For all cast iron, the sum of three cents per pound.

All broken material to belong to the party of the second part.

Finish. 125. The workmanship and finish throughout shall be thorough and of the very best, and any piece or part, however perfect it may be in other respects, if defective in workmanship, will be rejected.

Planed. 126. That part of the bed plate on which rests the three eighth inch bottom plate of the truss shall be planed or faced to a true plane surface. All abutting joints in top and lower chord shall be planed or faced.

Punching. 127. In punching rivet holes, the diameter of the die shall in no case exceed the diameter of the punch more than one sixteenth inch, and all holes must be clean cut, without torn or ragged edges.

Rivet Holes. 128. All rivet holes shall be so accurately spaced and drilled or punched that when the several parts are assembled a rivet one-sixteenth inch less in diameter than the hole can be entered hot into any hole without straining the iron by drifting. Occasional variations shall be corrected by reaming.

Rivet Work. 129. Whenever possible, all rivets must be machine driven. The rivets, when driven, shall completely fill the holes. The rivet heads shall be round and of a uniform size throughout the work. They shall be full and neatly made, and be concentric with the rivet holes, and thoroughly pinch the connected pieces together. The several pieces forming one built member must fit closely together, and when riveted shall be free from twists, bends or open joints. The angle irons forming the top chord must be bent at the different panel points to the proper angle. The lower chord shall have sufficient camber to allow for the deflection of the loaded truss.

Bolts and Nuts. 130. All bolts and nuts to be made from the best quality of soft steel. The nuts to be hexagonal and the heads square. Heads, nuts and threads to be standard size. All bolts shall have a washer under the heads or nuts, where in contact with wood.

131. All rods with screw ends shall be upset at the ends so that the diameter at the bottom of the threads shall be one sixteenth inch larger than any part of the body of the bar. Upset Ends.

132. All the angles, filling and splice plates must fit at their ends to the flange angles sufficiently close to be sealed, when painted, against the admission of water, but need not be boat finished. Angles, etc.

133. To support and hold purlins in place, short pieces of angle iron 3½ inches by 6 inches by ¾ inch shall be riveted to principals with two ¾-inch rivets, and purlins shall be fastened to them by ¾-inch bolts. The contractor shall furnish all bolts, each with one cast iron washer. Fastening and Supporting Purlins.

134. All the bed plates under fixed and sliding end must be fox-bolted to the masonry with 1¼ inch bolts. The contractor must furnish all bolts, drill all holes and set bolts to place with cement. Bed Plates and Anchors.

IRON GALLERY, LADDERS, ETC.

135. The galleries shall consist of three different sections, as follows:

1st. A lower or first gallery. (Sheet No. 7.)
2d. An upper or second gallery. (Sheet No. 7.)
3d. A balcony gallery. (Sheet No. 4.)

Details for above galleries will be found on Sheet No. 17.

136. The first gallery shall extend around the entire building on a level with grade (El. 115), and shall consist of brackets, railing, chains, posts, and wood floor. First Gallery

137. The wood floor shall be 4 feet and 2 inches wide and made of 1½ inch thick by 3 inch wide yellow pine flooring, and shall rest upon two girders and one channel bar, and both girders and channel bar shall be supported by cast iron brackets. The channel bar shall be 6 inches high, weighing 9½ pounds per lineal foot, and to this channel shall be bolted yellow pine nailing joists 2 inch by 6 inch; the bolts shall be ⅜ inch, with round head, nuts and washers, and shall be spaced three to each panel. The two yellow pine girders shall be 3 inch by 8 inch and notched so as to seat on the top of brackets.

138. Brackets shall be cast, according to detail, showed on sheet No. 17, and shall be firmly bolted to the stone-mason work with 1 inch by 10 inch expansion bolts, at top and bottom of each bracket.

The stone walls must be recessed sufficiently to give an even bearing for the backs of all brackets.

139. Railing shall be made of gas pipe and suitable fittings connecting same, made in accordance with details. Top and bottom rails shall be 1½ inch and 2 inch gas pipe; intermediate rails, 1¼ inch gas pipe; principal posts 2½ inch, and intermediate posts 2 inch diameter cast iron.

140. At the angle where the stairs commence this first gallery shall be constructed, on a radius, as shown on gallery plan, sheet No. 7, to make room for said stairway. A round hole must be made in this floor to suit stair column.

141. Suitable chain fastening gates shall be provided at all openings in gallery with suitable hooks, etc., chain to be of wrought iron ½ inch in diameter. There shall be two chains at each opening. See sheet No. 7.

Upper or Second Gallery.

142. The second gallery shall extend across south end of building, and terminate at one end with a spiral staircase, and shall consist of brackets, channels, railings, post and floor. The brackets shall be cast as per detail, shown on sheet No. 17, (scale, ¾ inch), and fastened to brick work by an expansion bolt at the foot and a bearing plate at the head. Upon these brackets shall rest a six inch channel bar weighing 9½ lbs. per lineal foot, and another bar of same size and weight shall be fastened to the brick work by expansion bolts. Upon these two channels the cast floor plates shall take their bearing. The railing, posts, etc., shall be made the same as specified for the first gallery. For a plan of this second or upper gallery, refer to sheet No. 7. The floor plates shall each be cast with three ribs; said ribs shall be spaced on centers, according to the length of the floor plates, and shall be located, one on each extreme edge and one in the center; all 3 inches deep and 1 inch thick.

Stairs.

143. Winding stairs shall consist of cast iron center column, treads, rail and newels.

144. The center column shall be cast ⅞ inch metal and be 7 inches in diameter, terminating at upper end with a newel, as shown on sheet No. 17.

145. The center column shall be supported by two 12 inch steel I beams, 42 pounds per foot, located diagonally across one corner of the stone foundation, with bolts and separators, and set in place before commencing the brick work. The col-

umn shall have a square iron flange on the lower end of 1 inch metal, and said flange must be firmly bolted to the steel I beams.

146. Steps or treads shall be cast without risers, but shall have thimble height of step, cast on each step, with tread nosing continued around.

147. These thimbles shall have freedom figured on drawing, and the vacant space shall be well and thoroughly calked with sulphur.

148. Steps shall be cast of ¾ inch metal, diamond pattern tread. Each step-thimble, bracket and flange shall be cast in one piece, each step being bolted to the next at connections. The first risers shall be housed into the wood floor, if necessary.

149. Stair rail shall be made of 2 inch gas pipe, bent to proper sweep and curve, terminating top and bottom at newels. Newels shall be cast iron ⅝ inch metal. All shall be executed according to drawings, each and every portion put up, bolted and secured in the strongest and most workmanlike manner, and to the satisfaction of the water commissioner.

150. The third or balcony gallery shall be constructed of wrought iron brackets, made of ½ inch by 2 inch metal, and fastened to the brick work with expansion bolts. It shall be provided with an oak tread board. This tread board shall be furnished by the carpenter and put in place by the gallery contractor. **Balcony [Gal]lery.**

151. This balcony shall extend across north end of building, as shown on section plan No. 4.

152. Two wrought iron ladders with ½ inch by 2 inch sides and ¾ inch round rungs, passing through side pieces and riveted, shall be furnished, put in place and properly secured. One ladder to start on the first or lower gallery and extend up and through the balcony gallery as per drawings. One ladder shall be located on the exterior of the building and commence about 10 feet from the ground and extend upwards to and be anchored into the fire-wall coping, as shown on elevation sheet No. 1. The details for these iron ladders will be found on sheet No. 17. **Ladder[s.]**

153. There shall be cast and set in place cast iron door sills for the doors in the north and south ends and the two large doors in each side. **Door Si[lls.]**

154. Sill for the south door shall be 5 feet 8 inches long and 3 feet 4¾ inches wide, ¾ inches thick, and cast in diamond pattern, with door saddle and seats for wood frame drilled for ½ inch expansion bolts.

155. Sill for the north door shall be 3 feet 6 inches long and 3 feet 4¾ inches wide, cast same as specified for south door.

156. Sills for the large doors shall be cast diamond pattern, 1 inch thick, and shall have a square flange on outside and inside edge as shown. These sills shall be cast in three separate sections, as shown and figured in sheet No. 17.

Hand Rail. 157. A hand rail made of 1¼ inch gas pipe shall be provided and put in place and continued along both sides of the building its entire length, 3 feet 6 inches above the traveler I beam. This railing shall project from the wall 6 inches, and be firmly bracketed to the wall at sufficient intervals to insure ample stiffness. The ends shall be secured to the wood window frames. See sheet No. 3.

Traveler Track. 158. The traveler track shall consist of an iron I beam, 8 inches in height, and weighing 34 pounds per lineal foot, Carnegie catalogue, No. 8 C, page 22, extending the entire length of building on each side. It shall be firmly bolted to the stone sill course with ¾ inch expansion bolts, and the space between the web of beam and sandstone sill shall be filled with hard burned brick, laid in the best of cement mortar.

159. Upon the top flange of this 8 inch I beam a flat top steel rail, weighing 52 pounds per lineal yard, shall be bolted, extending the entire length on both sides of the building. This rail must be drilled in each flange, and these flanges bolted with ¾ inch bolts into the flanges of the I beam. The rail shall be connected at joints with fishplates and bolts.

I Beams in Side Walls. 160. Two 8-inch I beams, weighing 34 pounds per foot, with bolts and separators, shall be built in brick work, as shown on plan and specified in clause No. 31, and covered with a ⅜-inch iron plate.

GENERAL CLAUSES.

Finish Complete. 161. All of the materials and work required for the full completion of the building herein specified, to the entire satisfaction of the water commissioner, shall be furnished and done by the contractor, and should anything not mentioned within this spec-

ification be necessary to fully complete the work, the same shall be furnished and done without extra charge.

162. No masonry work of any description shall be laid in freezing weather, except with special permission of the water commissioner. Frost.

163. All unfinished work shall be properly protected from injury by frost.

164. Any masonry work found damaged by frost shall be taken down and rebuilt at the cost of the contractor.

165. When the work is completed, the building, substructure and surrounding grounds shall be cleared of all rubbish caused by construction, and left in a neat and presentable condition for immediate use. Cleaning up.

166. Measures shall be taken by the contractor, whether required by city ordinance or not, to insure the safety of the public, by such precautions of fencing, watching, lights, etc., as the exigencies of the case may call for. Public Safety.

167. The contractor shall furnish, at his own cost and expense, all necessary centering and scaffolding, and remove same at the completion of the work. Erection.

168. Due facilities must be afforded the water commissioner for giving the lines, grades and points, and all stakes or marks given by him must be preserved undisturbed.

169. The contractor shall keep on the work, accessible at all times, the plans furnished him by the water commissioner, and a copy of these specifications.

170. At all times, when work is in progress, there shall be a foreman or head workman on the grounds.

171. Necessary conveniences shall be constructed for the use of the contractor's employees, and during the progress of the work herein specified the contractor shall not use or interfere in any manner with the present buildings, pipes or appurtenances of the waterworks.

172. The use of the railroad tracks and switches belonging to the waterworks will be permitted to the contractor for the work herein specified at such times only as will not interfere with the delivery, switching and handling of coal cars.

173. Particular care must be exercised in the protection of all finished work as the building progresses, such as exterior projections, cut stone, iron stairs and galleries, etc., which must be fully protected from injury or defacement during the erection and completion of the building.

174. The erection shall be carried on in such manner as will in no way interfere with the erection, completion and operation of the pumping engines or machinery. The extra cost of handling the erection in this manner must be included in the sum bid for the work.

175. The directions of the water commissioner as to the disposition of building materials and location of sheds, temporary buildings, etc., must be strictly observed.

Examination of work. 176. Whenever required by the water commissioner, the contractor shall furnish all facilities and labor to make an examination of any work, complete or in progress, under this contract. If the work so examined is found defective in any respect, or not in accordance with this contract and specifications, the contractor shall bear all expenses of such examination and of satisfactory reconstruction. If the work so examined is found to be in accordance with the contract and specifications, the expense of the examination and reconstruction will be estimated to contractor at a fair price, to be determined by the water commissioner. M. L. H.

171. General Specifications for Railroad Concrete Work. Cement concrete masonry, either with or without reinforcement with steel bars, is coming into such general use that a stone masonry specification in former editions of this work is here replaced by a general specification for railway concrete construction (not reinforced by steel rods), these being now in use (1902) by the Illinois Central Railway Company.

FOUNDATIONS AND EXCAVATION.

1. *Cofferdams,* where necessary as a protection against water in adjacent streams, etc., shall generally be built in accordance with detailed plans to be furnished in connection with each piece of work. Such cofferdams may consist of substantial or lighter structures in accordance with the amount of protection required or the risk to be incurred.

A—The more substantial cofferdams shall be built by driving rows of piles, spaced from three to five feet apart, centers; these to be securely connected together by lines of horizontal waling bolted on the outside, and sheet piling to be driven outside of these waling pieces and spiked or bolted to them as may be necessary. The sheet piling may consist of two rows of plank, the outer covering the joints between the inner planks —each row driven separate—or they may consist of a combination pile, made up of three pieces of plank, so built together as to make a tongued and grooved structure. In extreme cases, two rows of piles and two rows of sheeting would be used and a "puddling" of clay, or other suitable material, filled in between the two rows of the cofferdams.

B—Except in exposed situations piles may be omitted, and rows of sheet piles secured to waling timbers and properly braced, may serve the purpose of the cofferdam. In all cases all material for the cofferdam shall be furnished by the contractor, and shall be paid for by the lineal foot of pile furnished and driven, and thousand feet B. M. of timber, boards and planking used in the work; these prices to include bolts, spikes and all iron work required to hold same in place.

C—Generally such portions of cofferdams as do not obstruct the free flow of the water and are below ordinary low water may be left in the work. Portions of cofferdams extending above this level will generally be removed, and the cost of such removal is to be included in the prices named by the contractor for this work.

It must not be inferred by the contractors that cofferdams are not deemed necessary because not shown on the general or detailed plans. The contractor shall take up the question of their construction with the proper engineering authority, who shall determine the extent of cofferdam (or sheeting), bracing, etc., required, the work being constructed and paid for as described in other portions of the specifications.

2. Excavation—Either inside of cofferdams or in open pits, shall be taken down to such depth as may be specified by the engineer in charge. The contractor shall be prepared to sheet the sides of such excavation where cofferdams are not used, and to put in proper bracing to protect the same from caving; all timber and plank used for such sheeting to be paid for at the rates named for cofferdam material.

A—All excavated material shall be placed where it is available for filling, either in adjacent embankments, or around the masonry when completed; and such back filling as may be required against abutments, arches, etc., and which can be done

with the excavated material, shall be done by the contractor, and shall be covered by the price paid for excavation.

B—No allowance shall be made on account of slope to sides of excavations where the same are made in material already compacted, the contractor being expected, as above specified, to carry down the excavation to the proper depth, and to protect the same by sheeting and bracing. Where excavations are required to be made in loose or uncompacted material (including sand or sandy soil), the engineer in charge shall make a proper allowance for slope in such material, and shall measure all material removed in making such slope, as a portion of the excavation. The price paid for sheeting, bracing, etc., is to include the whole value of the material, the same being left in the work, if necessary, either as a mold for the concrete foundation, or as a protection against caving, during the process of excavation or of putting in the concrete.

C—If the contractor deposits any excavated material where it will obstruct the water-way or ditches adjacent to railroad embankments, or in any place not fully approved by the engineer in charge, he shall, at his own expense, remove the same before the completion of the work, and place it as may be directed by the engineer, or if the same is not done promptly upon the request of the engineer or inspector in charge of the work, it may be done by the railroad company's employees, and charged to the contractor and deducted from his estimates.

D—Excavation shall be classified as follows:

a. Dry excavation, including all materials which can be handled without pumping, and with which no water is mixed.

b. Wet excavation, including all material removed from cofferdams or pits, where pumping is required, or where water accumulates, either by seepage or from floods occurring during the progress of the work. The price paid for wet excavation is intended to cover the cost of all pumping which may be required, and shall include furnishing such pumping machinery as may be necessary for the work.

Where there is a rock foundation within reasonable distance below the surface of the ground, the excavation shall be carried down to the rock, and the surface of the same shall be roughly leveled either throughout the whole area of the foundation, or by making steps or benches at different elevations, separated by vertical risers; all loose rock, shale, clay, mud, etc., being removed before putting in the foundation concrete. Should water enter freely along the surface of the rock, the foundation may be prepared in sections, the concrete being filled in upon the rock surface, as each section is prepared for the same.

Care shall be taken that no clay, mud or earthy matter adheres to the rock or to the vertical joints between separate concrete sections, the object being to make a monolithic mass of the whole foundation, and to have the same cemented firmly to the rock.

c. Rock excavation, which shall include all solid rock, blasted or otherwise removed from the foundation, or all boulders or pieces of loose rock, weighing over fifty (50) pounds each.

CONCRETE MATERIALS.

3. Concrete Materials may be classified as follows:

A—*Crushed Limestone*, which shall be made by crushir tough, hard, clean limestone and screening same through tw inch meshes or holes.

The Engineer or Inspector in charge shall reject crushe limestone which may have any of the following defects:

a. Containing more than one (1) per cent. of earthy o clayey matter.

b. Containing more than twenty (20) per cent. of fine stone or stone dust, less than one-half (1-2) inch in size.

c. Containing more than five (5) per cent. of soft or rotten limestone which can be crushed or powdered up in the fingers.

d. Containing more than ten (10) per cent. of flat stone larger than two (2) inches in greatest dimension.

e. Containing more than fifteen (15) per cent. of crushed stone larger than specified (passing through a two (2) inch mesh), unless there be an equal amount of fine material less than one-half (1-2) inch size.

f. If any of the five classes of defective stone above named can be modified by mixture with additional material or by breaking large stone by hand, its use may be permitted under the direction of the Engineer or Inspector in charge.

g. The use of clean gravel in place of not more than one-half (1-2) of the specified amount of crushed limestone may be permitted at the option of the Chief Engineer, or his authorized representative; but the work shall be done under such special instructions as shall be given in each individual case, depending on the quality of the gravel used and other existing conditions.

B—*Crushed Granite.* This shall generally be used of two sizes: a fine crushed granite, to be used as a substitute for sand, and a coarser size, particles of which are not larger than three-fourths inches in greatest dimensions, and to be used as a substitute for crushed limestone in making bridge seats, pedestal stones, etc. All crushed granite shall be clean, entirely free from dust and earthy or clayey matter, and each grade shall

be of practically uniform size. This material shall always b handled on platforms or plank, or in some way kept entire free from admixture of earth, sand, etc.

C—*Sand for concrete* shall consist of clean, sharp sa ("pit" or "bank" sand being preferred), and sand shall not b rejected if containing occasionally pieces of small gravel. sand is preferred which will not pass through a sieve havi thirty meshes to the inch. Sand shall be free from earth alluvial matter; and, when tested by stirring with water or b rubbing in the hands, shall not show the existence of more th one-half of one per cent, of loam, clay or earth. No sand sh be used for the outside finish of any concrete which contai small particles of coal or of lignite, although sand of this cha acter may be accepted for foundation concrete, or for the i terior portion of any heavy piece of concrete work.

D—*Cement* shall in all cases be approved by the Engine of Bridges, and the Inspector in charge of the work shall r ceive a written approval before permitting concrete to be ma from any cement delivered. Where possible, cement shall b delivered in time to have samples properly taken and sent t the office of the Engineer of Bridges, for making the usu one-day and seven-day tests of neat cement. Contractors sh provide storehouses at the site of the several pieces of work i which to unload and store cement. Cement which is deliver on board cars must be unloaded promptly and stored in su warehouses, and the cars returned to the company's servic In no case will it be permitted to retain box cars on the wor for the storage of cement. Cars which may be so held sh be charged to the contractors at the rate of one dollar ($1.00 per day for each day after the second day so held unloade Contractors shall be responsible for the proper care of th cement after it has been received and stored, and any ceme injured through carelessness or neglect shall be rejecte promptly by the Inspector in charge. No brand of ceme shall be used in any concrete work which has not been a cepted in writing by the Engineer of Bridges, such acceptan to be based upon regular tests, where possible. The Inspect shall, from time to time, make small pats of pure cement, an of cement mixed with sand, to satisfy himself that the ceme actually used is of uniform character, and has not been in jured by exposure to weather or in any other way, and ma reject any cement which is wet or lumpy, or which fails to se properly in sample pats, and the contractor shall remove th same promptly from the work.

4. *Natural Cement Concrete* may be used where founda tions are entirely submerged below low water mark or wher

there is no risk of the same being exposed to the action of the weather by cutting away the surrounding earth. Natural cement concrete, however, shall be used only where a firm and uniform foundation is found to exist after excavations are completed. In all cases where foundations are liable to be exposed to the action of the water, or where the material in the bottom of excavations is soft or of unequal firmness, Portland cement concrete must be employed for foundation work.

(See specification for using railroad iron in foundation.) (Par. No. 16.)

5. *Natural Cement Concrete* shall usually be made in the proportions (by measure) of one part of approved cement to two parts of sand and five parts of crushed stone, all of character as above specified. For Portland cement concrete foundations one part of approved cement, three parts of sand and six parts of crushed stone may be used. Wherever in the judgment of the Engineer or Inspector in charge of the work, a stronger concrete is required than is above specified, the proportions of sand and crushed stone employed may be reduced, a natural cement concrete of one, two and four, and a Portland cement concrete of one, two and five being substituted for those above specified.

6. *Portland Cement Concrete* for the bodies of piers and abutments, for all wing-walls for same, and for the bench walls of arch culverts shall generally be made in the proportions (by measure) of one part of cement, two and one-half parts of sand and six parts of crushed stone. Where special strength may be required for any of this work, concrete in the proportions of one, two and five may be used; but all such cases shall be submitted to the judgment of the Engineer of Bridges, before any change from the usual specification is to be allowed.

7. For *Arch Rings* of arch culverts and for parapet head walls and copings to same, Portland cement concrete, in proportions of one, two and five, shall generally be used. Concrete of these proportions shall also generally be used for parapet walls behind bridge seats of piers or abutments, and for the finished copings (if used) on wing walls of concrete abutments, also for arch work in combination with I-beams or in combination with iron work for transverse loading.

8. *Bridge Seats* of piers and abutments and copings of concrete masonry which are to carry pedestals for girders or longer spans of iron work, shall generally be made of crushed granite and Portland cement, in the proportion (by measure) of one part of approved cement, two parts of fine granite screenings, and three parts of coarser granite screenings, the larger

of which shall not exceed three-fourths inch in greatest dimension.

8a. *Jacketing Work* shall consist of concrete in proportions of one (1) part of cement, two (2) parts of sand and either four (4) or five (5) parts of fine crushed stone (selected, if necessary, so that the largest pieces shall not be over one and one-half ($1\frac{1}{2}$) inches in greatest dimension). This material shall be used as a coating over masonry which is in bad condition, the thickness to be used varying from a minimum of four (4) inches to a maximum of, say, ten (10) inches, and generally averaging at least six (6) inches in thickness. It shall also be used for linings of tunnels or culverts in which the masonry is defective, or where added strength is required. This material shall be placed in molds which shall generally be built slightly in advance of the work. Special pains shall be taken in placing and ramming this material, so as to produce a smooth exterior finish, and to fill completely all crevices either small or large in the old masonry. No facing mortar will be required in this work, but a finished face shall be produced by spading and working the fine material of the concrete next to the mold. Material of this character shall be paid for by the cubic yard at a special price to be named in the proposal.

MIXING CONCRETE.

9. All concrete must be mixed on substantial platforms of plank or boards securely fastened together, so that the various materials of the concrete can be kept entirely free from admixture of foreign matter. Hand-mixed concrete shall not be made in batches of more than one yard in each batch. The proper amount of the several kinds of material shall be measured in some way which is entirely satisfactory to the Engineer or inspector in charge of the work, so that they may be satisfied that the requisite proportions of each kind of material are delivered for each batch of concrete. Satisfactory methods of measurement will be the use of headless and bottomless barrels for measuring sand and broken stone; the use of boxes into which the sand and stone may be cast and leveled off (the boxes then being removed), or the use of square and uniform sized wheelbarrows, expressly designed for this purpose. The measurement of sand and broken stone in the ordinary shallow, round bottom wheelbarrow will not be considered satisfactory, and shall not be permitted.

10. The detail of mixing concrete by hand shall be generally as follows: the proper amount of sand shall be measured out and spread upon the concrete platform, and the proper amount of cement shall be delivered and spread upon the same;

the sand and cement shall be turned over dry, either by means of shovels or hoes, until they are evenly mixed. They shall then be wet and made into a rather thin mortar, and shall then again be spread into a uniform and thin layer upon the concrete platform. The proper amount of concrete stone (the same having been previously drenched with water) shall be spread upon the mortar, and the whole shall be turned over at least twice, either by shovels or hoes, before it is loaded into wheel-barrows, or in any other way taken to be placed in the work. In wetting the mixture of sand and cement to make the mortar, and in wetting the subsequent mixture of stone, sand and cement (if necessary), a spray or sprinkler shall be used. The water must not be dashed upon the mass in buckets or large quantities, or by means of a jet. The inspector shall insist that the resultant mixture of sand, cement and stone is as nearly as possible uniform in character, the mortar being equally distributed throughout the mass of the stone. The inspector shall also see that the mixture is neither too wet nor too dry. It should be of such a consistency that, when thoroughly rammed, it will quake slightly, but it should not be thin enough to quake in the barrow, or before ramming. The inspector shall satisfy himself that the proper proportions of cement, sand and stone are used, checking from day to day or from time to time with the total amount of each which is received and used.

11. Machine-mixed concrete shall be made of the same general consistency as the hand-mixed concrete above specified. Proper precautions shall be taken to see that the requisite proportions of the different ingredients are used. If machines are used which are not provided with devices to deliver each of them, the process of making the concrete shall generally be as follows: The proper amount of sand, cement and stone for a batch not to exceed one yard of concrete shall be delivered on the platform, and roughly mixed together so that when the dry mass is cut down and delivered to the mixer by means of shovels, proper amounts of each of the ingredients are handled in each shovelful.

It will not be regarded as a satisfactory process to deliver crushed stone, sand and cement at random to the mixer, without taking some special means, as above described, to insure the delivery of the proper quantities of each ingredient as nearly as may be simultaneously.

MOLDS.

12. MOLDS of substantial character shall be made in which to construct all concrete work. The material for these molds shall be furnished by the contractor, and the expense of furnish-

ing this material and of constructing and removing all molds shall be covered in the price per yard paid to the contractor for the several classes of concrete work called for. The face of the mold next to the concrete shall be finished smooth, planks which are dressed at least on one side being employed for this purpose. Material for the molds shall be of sufficient thickness, and the frame holding them shall be of sufficient strength, so that they shall be practically unyielding during the process of filling, tamping, etc. The different parts of the frame work for the mold may be fastened together, if desired, by tie rods or wires extending through the concrete. If tie rods are used they shall be so designed that no iron work will be left outside of the concrete or within less than two inches from the face of the same when the molds are removed. This may be accomplished by sleeve nut connections which will permit the removal of the projecting ends of bolts or rods, etc., leaving only small holes in the concrete which can be stopped with pointing mortar after removing the molds. Another satisfactory method of bracing molds is to construct them with cross ties between the front and back, these ties to be placed at frequent intervals above the lower portion of the mold and to be removed as the concrete is built up, the studding out of which the molds are constructed being sufficiently long to extend above the top of the finished masonry, and at least one set of ties being used above this level. In general 2-inch plank, sized to approximately $1\frac{3}{4}$ inch thickness, shall be used for the facing of all molds, and studding for frames shall be placed at intervals not more than 4 ft. apart. The planking forming the lining of the molds shall invariably be fastened to the studding in perfectly horizontal lines, the ends of these planks shall be neatly butted against each other, and the inner surface of the mold shall be as nearly as possible perfectly smooth, without crevices or offsets between the sides or ends of adjacent planks. Where planks are used a second time, they shall be thoroughly cleaned, and, if necessary, the sides and ends shall be freshly jointed so as to make a perfectly smooth finish to the concrete.

13. The molds for projecting copings, bridge seats, parapet walls, and all finished work shall be constructed in a first-class, workmanlike manner, and shall be thoroughly braced and tied together, dressed surfaces only being exposed to the contact of concrete, and these surfaces shall be soaped or oiled if necessary, so as to make a smoothly finished piece of work. The top surfaces of all bridge seats, parapets, etc., shall be made perfectly level, unless otherwise provided in the plans, and shall be finished with long, straight edges, and all beveled surfaces or washes shall be constructed in a true and uniform manner.

Special care shall be taken in the construction of the vertical angles of the masonry, and where I-beams or other iron work are not used in the same, small wooden strips shall be set in the corners of the mold, so as to cut off the corners at an angle of forty-five (45) degrees, leaving a beveled face about one and one-half ($1\frac{1}{2}$) to two (2) inches wide, instead of a right angled corner.

14. Where wing walls are called for which have slopes corresponding to the angle of repose of earth embankments, these slopes shall be finished in straight lines and surfaces, the mold for such wing walls and slopes being constructed with its top at the proper slope, so that the concrete work on the slope may be finished in short sections, say from three to four feet in length, and bonded into the concrete of the horizontal sections before the same shall be set, each short section of sloped surface being grooved with a cross line separating it from adjacent sections. It will not be permitted to finish the top surface of such sloped wing walls by plastering fresh concrete upon the top of concrete which has already set, but the finished work must be made each day as the horizontal layers are carried up, to accomplish which the mold must be constructed complete at the outset; or, if the wing wall is very high, short sections of the mold, including the form for the slopes, must be completed as the horizontal planking is put in place.

15. Foundation concrete may be put into excavations without the use of molds, provided the sides of the excavation are reasonably true and the material is sufficiently firm, so that the concrete may be rammed thoroughly without yielding of the adjacent earth. Where a cheaper kind of concrete is used for foundation work, the top of the same shall be finished smooth and level, the corners and edges being thoroughly rammed and compacted, and the whole surface filled full of mortar. It will not be satisfactory to leave a honey-combed surface or one on which a lot of loose concrete stone is left scattered about.

It is not expected that the surface of such foundation work shall be accurately leveled unless cut stone masonry is to be built upon it, but the Inspector must insist that that portion of such foundation concrete which projects outside of the masonry which is to be built upon the foundation must be thoroughly rammed and compacted, and must have a finished surface. If this cannot be accomplished without constructing a mold for the upper portion of such foundation, the contractor shall furnish material and construct such mold, and the cost of the same shall be included in the price of the foundation concrete.

16. *Iron Rails* to be furnished by the Railroad Company shall be laid and imbedded in such manner as may be specified

in such foundation concrete as in the opinion of the engineer of bridges needs such strengthening, and no extra charge, except the actual cost of handling the same, shall be made by the contractor for such work, but the volume of such iron shall be estimated as concrete.

17. Where I-beams are to be placed in the angles of concrete piers as a protection against ice, drift, etc., these shall be set up and securely held in position so that they will extend one foot or more into the foundation concrete. The planking of molds shall be fitted carefully to the projecting angles of these I-beams and small fillets of wood shall be fitted in between the inner faces of the mold and the rounded edges of the I-beam flanges so that no sharp projecting angle of concrete will be formed as the work is constructed.

These fillets may be made in short pieces and fastened neatly into the mold as the layers of concrete are carried up. Such I-beams will generally be furnished of sufficient length to extend at least six inches above the top of the battered masonry into the concrete copings, and special pains shall be taken to tamp the concrete thoroughly around the I-beams, and to finish the coping above and around the ends of the same, so as to make a compact and solid bearing against the iron work.

18. Where anchor bolts for bridge seat castings are required, they shall be set in place and held firmly as to position and elevation, by templets, securely fastened to the mold and framing. Such I-beams and anchor bolts shall be embedded in the concrete work without additional expense beyond the price to be paid per yard for the several classes of concrete in which such iron is placed, the volume of iron being estimated as concrete.

19. After the work is finished and thoroughly set, all molds shall be removed by the contractor. They shall generally be allowed to stand not less than forty-eight hours after the last concrete work shall have been done. In cold weather, molds shall be allowed to stand a longer period before being removed, depending upon the degree of cold. No molds shall be removed in freezing weather, nor until after the concrete shall have had at least forty-eight hours, with the thermometer at or above 40 degrees F., in which to set.

PLACING CONCRETE.

20. Concrete shall generally be placed in the work in layers not exceeding six inches in thickness, and, in general, one layer shall be entirely completed before another one is commenced. If delivered by wheel-barrows it shall be dumped as closely as possible where required, so as to avoid as much as

possible the handling or turning over the same by means of shovels within the excavation or mold. Where it is not practicable entirely to complete one layer before commencing a second one, a plank, six inches wide or more, shall be securely fastened into the excavation or mold, against which the end of the layer of concrete shall be rammed, thus providing for a vertical joint in this layer of concrete, and if a second layer has to be stopped short of the full length of the work, a second cross plank, placed at least one foot back from the end of the first layer, shall be secured to the excavation or to the mold, against which to ram the second layer of concrete. Layers of concrete masonry must not be tapered off in wedge-shaped slopes, but must be built with square ends in the method above described, and the surface of each projection shall be finished hard and smooth, and flushed full of mortar, no porosities or loose stone being left thereon. Layers must not be made of greater thickness than six inches, unless specially permitted, and each layer must be thoroughly rammed, and the concrete must be of such consistency that heavy ramming will produce a slight quaking action. In other words, the concrete must be so thoroughly compacted that there will be no pores or open spaces between the stone of which it consists, which are not thoroughly filled with mortar.

The inspector shall insist upon the thorough compacting and ramming of all concrete, and shall see that a sufficient number of men, furnished with suitable rammers, are assigned to this work. Enough men shall be employed ramming, so that each batch may be spread and rammed before another batch is dumped within the mold. The ramming must be completed as the work progresses.

21. Foundation concrete, if put into excavations which are not protected by molds, need not have any special attention given to the finish of the concrete against the earth around it. Where it is necessary to use molds in the construction of foundation work, the finer material of the concrete shall be worked to the outer portion of the mass against the molds, so as to insure the filling with mortar of all pores or open spaces between the concrete stone. As before described, the top surface of all foundation concrete shall be finished, so that no loose stone or open and porous places are left upon the same, especially in the portions of the foundation which project outside the upper portion of the work. If necessary, the Inspector shall have the contractor make batches of mortar, consisting of one part of cement to three parts of sand, the same being thoroughly mixed, and shall cover the whole surface of the foundation concrete with enough of this mortar to flush full all such open, porous places.

22. *A Facing of Mortar,* consisting of one part of cement (by measure) to two parts of sand, shall be put in next to the molds, for all Portland cement concrete work for piers, abutments, arches, wing walls, parapet walls, and any other places where directed by the engineer in charge, to form a finish for all such parts of the above classes of work as are to be exposed to the weather, or which are liable to become so exposed. A similar facing shall be used for the top surface of all concrete masonry not finished with granitoid work, and such surfaces shall be finished in the style of sidewalk work.

It is not intended to use such a facing on the backs of abutments or wing walls, against which earth filling is to be placed, and where the same must necessarily be maintained, but the same shall be used for the faces and for the upper twelve inches on the backs of all wing walls, for the backs of parapet walls, for the intrados of all arch work, and as a plastering on the outside of the same, and in all such places where the washing away of earth may expose concrete work to the action of the weather. It is not intended to use such facing for any copings, bridge-seats, parapets, etc., which are to be of granitoid construction. The exact thickness of one and one-half inch for this facing shall be secured in the following manner: A piece of sheet iron six inches in width (the height of one course of concrete), and of any convenient length, say from six feet upwards, having small angle irons, the projecting leg of which shall be one and one-half inches in width riveted to its face, at intervals of about two feet, and provided with handles standing above the upper edge at or near each end, shall be furnished by the contractor for use at each piece of work where necessary. This piece of iron plate, if placed with the projecting angles against the face of the mold, will leave a space of one and one-half inches between it and the mold. This space shall be filled with the mortar required for the facing, which mortar shall be mixed in small batches from time to time as needed for the work. When the space between the iron plate and the mold is filled and tamped with a shovel or other tool to insure complete filling of the whole space between the iron plate and the face of the mold, and when the layer of ordinary concrete is backed up against this iron plate, it is to be withdrawn by means of the handles and the whole mass of concrete rammed in one uniform layer. The Inspector shall see that the space of one and one half inches is entirely filled with the mortar, which should be of a consistency so that it will flow somewhat freely. At the same time this mortar must not be made so thin that the crushed stone may be forced through it in the process of ramming. By using the mold in the manner above described, the face of each

layer may be made of exactly the right amount of mortar, and the proper thickness of the layer may be accurately determined. The intention is that the facing and the backing shall be rammed and set together. In no case is one to be put in advance of the other, or so that either may set before the other. In no case shall the Inspector or Engineer in charge permit any work to be finished by plastering mortar on concrete which has set, but should it become necessary at any time to refinish a surface which has set, it shall be picked off so that at least three (3) inches of mortar can be added, and the surface of the old concrete shall be roughened and thoroughly wet before new material is added, such new material being mortar as specified for facing.

23. Layers of concrete shall be kept truly horizontal, and if, for any reason, it is necessary to stop work for an indefinite period, it shall be the duty of the Inspector and of the contractor to see that the top surface of the concrete, is properly finished, so that nothing but a horizontal line shall show on the face of the concrete, as the joint between portions of the work constructed before and after such period of delay. If, for any reason, it is impossible to complete an entire layer, the end of the layer shall be made square and true by the use of a temporary plank partition, as specified in paragraph twenty (20). No irregular, wavy or sloping lines shall be permitted to show on the face of the concrete work as the result of constructing different portions of the work at different periods, and none but horizontal or vertical lines shall be permitted in such cases.

24. Where concrete is to be put into a foundation below water level, all water shall as far as possible be removed from the excavation. If it is impossible by means of the ordinary pumping facilities to control the flow of water, the excavation may be taken out in sections, and the concrete may be placed in the foundation, section by section. Special care should be taken to ram thoroughly the bottom layer of concrete, and to remove all mud and clay from the vertical face of each section of concrete, as additional sections are excavated and prepared for addition of concrete work. Where the foundation is soft, as, for example, where piles are used, either fine or coarse broken stone may be spread over the bottom of the excavation and thoroughly rammed into the earth before putting in any concrete. In no case shall a dry mixture of sand, cement and crushed stone be put into a foundation. The concrete may be mixed with a less proportion of water, but should not be placed in the foundation without thorough mixing. Where strata of gravel and sand permit the entrance of water into the foundation with such freedom that small sections of the same cannot be

excavated and pumped out for concreting, a grout of pure cement or of a mixture of cement and one or two parts of sand may be injected through a pipe into the loose gravel and sand in the bottom of the foundation; this work being done while the excavation is filled with water. The pipe through which this grout is passed should be pushed a few inches below the surface of the gravel, and a bucketful or more of grout should be poured down through the pipe, the pipe being then moved one or two feet, and the operation repeated, distributing the grout over the whole area of the bottom to be thus cemented, and the work then should be allowed to stand for twenty-four to thirty six hours. It will generally be found that the sand and gravel will be converted into a water-tight concrete, permitting the pumping out of the excavation.

25. Where it is impossible to complete parapet walls, copings, etc., on account of stringers or other wood or iron work necessary to maintain structures over which tracks are in use, all work shall be finished to horizontal and vertical lines, and with surfaces filled with mortar, so that when possible to complete the concrete work, the joint between the new and the old work shall show nothing but straight, level and vertical lines.

26. *Expansion Joints.*—Where masonry structures are more than one hundred feet in length, such provision for expansion joints shall be made as may be specified by the Engineer of Bridges or his assistants. Generally in the construction of large arches, or of smaller, long concrete arches, the work shall be subdivided into sections of approximately twenty-five feet in length, each section being separated from the adjacent one by a vertical joint extending entirely through the bench walls, arch rings, etc.; but the foundation work shall be stepped as previously explained, and made in one continuous monolithic mass. Temporary vertical partitions shall be put into the molds, against which the concrete shall be thoroughly rammed, where arch culverts are subdivided into short lengths, as above specified, these partitions being removed as each section is completed, and the next adjacent section being rammed against the concrete already constructed and set. The joints thus made shall not be flushed with mortar, nor shall any attempt be made to make the fresh concrete adhere to the older work, but a small beveled strip of wood shall be set in the angle next to the temporary partition so as to make a "V" groove, defining the joint and leaving a depth of, say, three-fourths ($\frac{3}{4}$) of an inch on the finished face of the work, it being the intention that any contraction shall open or that settlement shall effect a sliding action at such vertical joints, rather than to break up the concrete in the separate sections.

POINTING.

27. After the molds are removed, if there should be found any small pits or openings on the exposed faces of the concrete (or if bolts are used for securing the molds the ends of which are removed, leaving small holes), all such holes, pits or porous places shall be neatly stopped with pointing mortar, made of equal parts of cement and sand and mixed in small quantities to be used before the same shall set. Although it has not been specified to use a facing of mortar for such masonry as is to be permanently buried or covered by earthwork, such ma—
shall not be constructed and left with pores and honey-
surfaces. All such pores and openings shall be stopped
pointing mortar, composed of one part of cement and t
of sand, the same to be neatly filled into all op
smoothly finished, in advance of any filling against

NAME PLATE AND DATE.

28. A name plate and date shall be furnished by the contractor and put upon one piece of masonry at each bridge or job constructed by him, such plate to be of brass or copper or other durable metal, furnished with bolts or projections on the back to be buried in the concrete and to secure it firmly to the same, and having on it the contractor's name and the date of the year in which the concrete work is constructed. These plates should be placed upon the parapet walls of abutments, concrete arches and pipe culverts, and upon the ends of the bridge seats of piers, where they can be plainly seen and easily read. These should be set as the concrete work is finished and should be level with the surface of the same.

EXTRA WORK.

29. It is the intention of the foregoing specifications that work of all kinds shall be done by unit prices. It shall be paid for at rates per unit of measure of the several kinds of work required. Wherever, in the judgment of the Engineer in charge, such prices are unfair to the contractor, the conditions shall be fully explained to the Engineer of Bridges, whose permission shall be obtained in writing for all extra work to be done. Generally such work shall be done at the actual cost, and the contractor shall be allowed ten (10) per cent. in addition, to cover superintendence, the use of tools, etc. No other rate will be allowed, unless specially provided when the work is ordered.

30. A daily report of forces employed and material used in all extra work shall be made by the Foreman on the work to the Assistant Engineer or Inspector in charge of the work,

who shall check the same from day to day and settle all disputed questions as to labor and material used. A return of all such extra work shall be made by the contractor (or by his foreman) at the end of each month, which shall be given to the Engineer or Inspector on the work for certification, and shall be sent to the Engineer of Bridges, with the estimate of work done at contract prices, so that the monthly estimate may cover all work done during the month. In general, all bills for extra work claimed to have been done by the contractors shall be rendered monthly and shall be certified to by the Engineer or Inspector in charge of the work.

CLASSIFICATION OF PROPOSALS.

31. Contractors will be requested to name prices for the following materials and kinds of work:

a. A price per lineal foot for piles furnished and driven in cofferdams and foundations.

b. A price per M. ft. B. M. for timber, plank, boards, etc., used in cofferdams, sheeting, etc.

c. A price per cubic yard for dry excavation.

d. A price per cubic yard for wet excavation.

e. A price per cubic yard for rock excavation.

f. A price per cubic yard for foundation concrete of natural cement, proportions of one, two and five.

g. A price per cubic yard for foundation concrete of natural cement, proportions of one, two and four.

h. A price per cubic yard for foundation concrete of Portland cement, proportions of one, three and six.

i. A price per cubic yard for foundation concrete of Portland cement, proportions of one, two and five.

j. A price per cubic yard for Portland cement concrete in piers, abutments, bench walls of arch culverts and wing walls, including mortar facing, proportions of one, two and one-half and six.

k. A price per cubic yard for Portland cement concrete in arch rings of arch culverts, parapet walls, copings, etc., proportions of one, two and five (including mortar facing for same).

l. A price per cubic yard for granitoid concrete as specified for bridge seats and copings, proportions of one, two and three.

32. The prices for all kinds of concrete (except foundation concrete) are to include all molds, framing, tie rods, braces, etc., required in constructing concrete, in accordance with the detailed plans.

MARCH, 1900.

ACCEPTED .... Contractor.

172. Specifications for Railway Road-bed. The following specifications cover all the work of building a road-bed of a railroad including clearing, grading, and all fixed structures which make a part of the road-way with the exception of span bridges. It is the latest form (1902) used by one of the leading and most careful railroad consulting engineers in the country and a past President of the American Society of Civil Engineers. The general stipulations are not included here.

CLEARING AND GRUBBING.

The whole width of the right-of-way shall be cleared of all trees, stumps, logs, brush and other perishable matter, and all fences and buildings which come within the limits of the right-of-way shall be removed to or beyond these limits.

Under embankments less than three feet in height, and wherever there is an excavation of any depth, all trees, stumps and brush shall be grubbed out, and under embankments three feet or more in height they must be cut off close to the ground.

All timber on the right-of-way is the property of the Railway Company or of the owners of the land, and in the latter case may be removed by them within a reasonable time. All timber not so removed shall be cut by the Contractor into such lengths and piled in such manner as may be directed by the Engineer. All stumps, brush and worthless timber are to be burnt up when it can be done with safety; but in no case are tree tops or other rubbish to be thrown onto adjoining land, except with the consent of the land owner.

Clearing shall be paid for by the lump sum or by the acre, the price paid therefor being understood to include all necessary grubbing.

The removal of fences excepting hedges shall be done without charge, and that of buildings at such price as may be agreed upon or may be fixed by the Engineer in the absence of an agreement.

Hedge fences must be grubbed out within the limits of the right-of-way and completely burned up, for which a price of..... per hundred feet will be paid.

GRADING.

General Requirements.—Under the head of grading will be included all excavations and embankments needed for the formation of the road bed and for all accessory works, such as foundation pits, new channels for streams, road crossings and new roads which may be directed by the Engineer.

rule the following side slopes and widths at grade ed: In earth excavations 22 feet at grade, with side one horizontal to one vertical. In rock excavations t grade, with side slopes of one-fourth horizontal to cal.

mbankments the side slopes shall be one and one-half orizontal to one vertical, and the width at grade shall be for anks less than six feet in height, sixteen feet; for banks six feet in height and up to sixteen feet in height, eighteen feet; and in banks over sixteen feet in height, twenty feet; but these widths and slopes may be varied at the discretion of the Engineer.

The road bed and the slopes of all excavations and embankments must be neatly and truly finished to the stakes and directions given, and no wheel tracks or other depressions left which will lead the water along the road. After finishing the work the contractor must build such fences or other obstructions as will prevent teams from driving along the road and maintain them until the final acceptance of his work, and he must repair any damage resulting from neglect of this precaution.

In rock cuts the Contractor will, as a rule, be required to carry excavations six inches below the ordinary sub-grade, in order to allow for ballasting. If of suitable quality, the rock thus excavated shall be broken up so that it will all pass through a two-inch ring and be left in good surface to receive the track. For this breaking and surfacing an additional allowance of 25 cents per yard measured in excavation will be allowed.

Excavation and Ditching.—All material taken from excavations, whether for the road bed or for ditches, new channels, or other accessory works, shall be used as the Engineer shall in each case direct. Where there is any surplus beyond what is needed for the embankments, which for this purpose may be widened to any extent, it shall be deposited in spoil banks. All spoil banks shall be sloped on the side next the road with a slope not steeper than one and one-half to one, and be kept at least six feet from the edge of the excavation.

The Contractor when so directed by the Engineer, shall deposit at such convenient points as he may designate, any stone or other valuable material which may be found in the excavations. All material so deposited shall be the property of the Railway Company, and the Contractor will be held responsible for its safe keeping until removed by said Company, or until this contract is closed.

All falls or slides from the sides of the excavations shall

be taken out by the Contractor, and, except when due to his carelessness or neglect, will be paid for at the same price as other excavation.

Side ditches along the road bed in excavations shall be cut of such widths and depths as the Engineer may direct. Drainage ditches outside of the excavations as well as new channels for streams shall be made whenever directed by the Engineer.

Excavation for foundation pits under water or for deepening new channels in running water will be paid for at such price as may be agreed upon, or as may be fixed by the Engineer in the absence of an agreement. But in either case the price paid shall cover the cost of all pumping, bailing and all labor and materials used in such excavation.

Embankments.—As a rule earth embankments, except as herein otherwise specified for filling over culverts, must be built with wagons or scrapers. The Engineer, however, may permit the use of cars where such use will materially expedite the work or reduce its cost.

All embankments must be commenced and carried up to the top at full width, the sides being kept at all times as high as the center, and be built up in layers not exceeding four feet in thickness, in such manner as to make the bank as compact as possible. They shall also be carried to such height above the final grade line as the Engineer may deem necessary to provide for shrinkage, washing and settlement, and be maintained at their proper height and width until accepted by the Chief Engineer, but the computation of quantities shall be made from the true cross sections to which it is presumed the embankments will finally settle.

In filling over masonry culverts care must be taken to avoid injury or distortion to the masonry, and if directed by the Engineer, the earth shall be wheeled or placed with shovels over and around the culverts and be carefully rammed in thin layers. For such wheeling and tamping such allowance will be made as the Engineer shall deem just.

No logs, stumps, brush or other perishable materials will be allowed in any embankments.

Borrowing.—In case sufficient material cannot be obtained by hauling from the excavations, the deficiency may be made up by borrowing, subject, however, to the direction of the Engineer, in each case as to the place from which to borrow.

Borrow pits alongside the railroad shall not be brought nearer to the toe of the embankment than six feet, nor nearer to the right-of-way line than two feet, and shall have a slope next the railroad not steeper than one and one-half to one. Borrow pits must be excavated neatly, irregular edges and deep

holes being avoided, and they must be so connected together as to give efficient drainage along the railroad.

Classification of Materials.—The materials found in excavations will be classed as Solid Rock, Loose Rock and Earth, the Chief Engineer being in every case the final judge as to the class to which any material belongs.

Solid Rock will include all loose boulders containing one cubic yard or more, and all hard rock in compact strata or ledges exceeding six inches in thickness, which, in the judgment of the Engineer, cannot be loosened except by blasting.

Loose Rock will include all loose boulders containing more than two cubic feet, and less than one cubic yard, and all materials requiring the use of pick and bar, or which cannot be plowed with a strong ten-inch grading plow, well handled, drawn by a good six-horse team.

Earth will include all materials of whatever kind which do not clearly belong to one or the other of the foregoing classes.

Whenever material of any kind other than Earth is found in an excavation, the Contractor shall at once notify the Engineer in charge, so that he may make the necessary measurements to determine its quantity. If the Contractor shall fail to give such notice, the Engineer may presume that the measurements taken at the time he first sees the material in question will give the true quantity.

Solid or Loose Rock excavation will be paid for by adding to the price of Earth excavation an extra price named in the contract, which shall cover the additional cost of loosening and loading the material.

RULES FOR MEASUREMENTS.

For payment, earth work will be divided into three classes, as follows:

All material taken from excavations of every kind, excepting borrow pits, will be classed and paid for as excavation.

Earth taken from borrow pits opened to furnish material not obtainable from other sources and delivered in embankment, will be classed and paid for as earth borrowed. So much of the material from excavations or borrow pits as is necessarily hauled more than three hundred feet, will be classed as material overhauled, and a price in addition to that for earth excavated or earth borrowed will be paid for the hauling, said price to be a price per cubic yard for each one hundred feet of haul in excess of three hundred feet.

Earth excavated will be measured in excavation; earth borrowed, where the whole embankment is made of earth, will

be measured in embankment. Where the bank is made partly of rock and partly of earth, the amount of earth borrowed may be determined either by measuring the borrow pit or by measuring the embankment, as in the judgment of the Engineer will give the greater certainty.

Solid rock and loose rock will be measured in excavation, and in computing overhaul, the number of yards hauled will be determined by the measurement in excavation and the distance hauled determined by the volume of the embankment actually made from it.

MASONRY.

General Conditions.—All masonry must be built in accordance with the plans and dimensions furnished by the Engineer, and be subject also to the directions of any Superintendent or Inspector of Masonry appointed by him.

All masonry will be paid for by the cubic yard, measured in the finished work, and the amount so paid shall be in full for all labor and materials used in the work, including cost of scaffolding and centering, and the repairing of all damages to the unfinished work from floods or other causes.

Materials.—All stone used in masonry must be sound and durable stone, approved by the Engineer, and be used in blocks as large as the quarries will furnish, or as may be necessary to comply with these specifications or the plans of the particular structure.

For brick masonry only the best quality of strictly hard dark red bricks shall be used, all to be of uniform texture throughout and free from lime or other impurities. No soft bricks will be allowed in any part of the work, nor shall any clinkers or any broken bricks be brought upon the ground. Bricks broken afterwards in handling shall be used in such manner only as the Engineer or the Inspector may direct. If so required, the Contractor shall furnish men at his own expense to cull the bricks under the direction of the Inspector, and all rejected bricks must be at once removed from the line of the work.

Unless otherwise agreed, cement for use in all masonry will be furnished by the Railway Company to the Contractor, and be delivered at.................................... For each barrel of cement so delivered the Contractor will be charged...................dollars to be deducted out of any moneys due under this contract. Cement, after it is received by the Contractor, must be kept under cover and dry until

used. If allowed to become wet or damaged from any cause, it will be rejected and must not be used in the work.

Mortar for use in the masonry, except when otherwise specified, shall be composed of one part cement to three parts clean, sharp silicious sand, from which all sticks and gravel have been removed by screening. The proportions of cement and sand shall be determined by measurement, and shall be thoroughly mixed dry, in a suitable box. Enough water shall then be added to give the mortar the proper consistency, care being taken to avoid an excess of water. All mortar shall be made fresh for the work in hand, and no mortar used which has begun to set.

Concrete will be made of clean, hard, angular broken stones, of not more than two inches in the greatest dimension, mixed with smaller stones not less than one-fourth of an inch in the greatest dimension, and with mortar in such quantity as to be from five to ten per cent in excess of the volume necessary to fill the void spaces of the stone, the amount of mortar required for this purpose to be in every case determined by the Engineer. When mixed by hand, concrete must be mixed on tight-jointed plank platforms. The mortar will first be made as directed in the preceding paragraph, and the stone having been washed clean will then be added while wet, and the whole mass turned over twice with shovels. Concrete may also be mixed by machine, provided that in the judgment of the Engineer the mixture is as complete and the result in all respects as good as if done by hand in the manner just described.

Forms.—The forms for shaping concrete work shall be made of pine planks twelve inches wide and not less than two inches thick, dressed to a smooth surface on one side and both edges. The dressed face shall be on the side next the concrete. The forms shall be framed and braced in accordance with plans furnished, or approved, by the Engineer.

Depositing and Ramming Concrete.—All concrete shall be deposited in layers not exceeding nine inches thick, and be rammed until the mortar flushes to the surface. If, when this is done, the mass quakes, the amount of water shall be reduced until this is avoided.

In placing concrete upon the foundation already built, the foundation shall be swept clean and then covered with a wet layer of mortar not less than one inch thick to make a close joint between the wall and the foundation.

In filling a form the work shall be carried on continuously so that it shall be a monolithic mass without horizontal joints. The part next the outer side or showing face of the wall shall

be filled with facing mortar, made of one part Portland cement and two parts sand. The thickness of the facing shall not exceed one and one-half inches, nor be less than three-fourths of an inch. The facing and backing must go on simultaneously in the same horizontal layers. In order to guage the thickness of the facing accurately, a light board or diaphragm of thin metal and with convenient handles shall be set on edge parallel to, and one and one-half inches from the front wall of the form. Facing material shall be deposited in the space between this board and the form. Concrete for the backing shall then b deposited and spread against the back of the board, which sha then be withdrawn and the whole mass thoroughly rammed s. as to bond the facing and backing by destroying the surfac of demarkation between them, but no stone must be forcec nearer to the front wall of the form than three-fourths of an inch.

Concrete or mortar shall not be made when the temperature is lower than 35 degrees Fahrenheit in the shade, or when rain is falling on it. Forms and molds must be left in position for not less than four days after the concrete is deposited. Freshly deposited concrete shall be protected from the direct rays of the sun and from wind by boards or tarpaulins, and as soon as a section of wall is completed the top must be covered, with a layer of damp sand not less than two inches thick, which shall be kept moist until the concrete has set.

The walls of the wooden forms shall be kept well wet during the progress of the concrete work.

Brick Masonry.—In laying brick masonry every brick must be cleaned and thoroughly wet just before being laid. Every brick shall be laid with a "push joint," that is, by placing sufficient mortar on the wall and forcing the bricks into it in such a manner as to completely fill every joint with mortar, whether at the bottom, side or end of the brick. The joints shall be made as nearly as possible of uniform thickness, not exceeding half an inch. The face joints shall be left full and be neatly struck. All unfinished work must be racked back in courses, unless otherwise directed, and when new work is to be joined to it the surface of the unfinished work must be cleaned and wetted.

For the inside of arches and for the exposed face of all walls only the smoothest and hardest bricks, carefully selected for that purpose, shall be used, great care being taken to lay them to true cylindrical and plane surfaces.

In arches the bricks shall be stretchers so laid as to break joints with those in adjoining courses. All other walls shall

be laid in English bond, that is, with alternate courses of headers and stretchers, each course breaking joints with the course below. No broken bricks shall be used in the face of any wall, except when necessary to make closures or to break joints.

Foundations.—Unless otherwise specially agreed or directed, the foundations for all masonry shall be prepared by the Masonry Contractor, and in case a natural bed sufficiently firm is not found at a reasonable depth, he shall prepare such artificial foundation of timber, concrete or other material as the Engineer may direct.

Where a price is named in this contract for timber or other materials used in foundations, it is intended to cover every expense of furnishing the material and putting the same in place, the amounts paid for being those found in the finished structure. And where a price is named for excavation in foundation pits below water, it is intended to cover the cost of pumping, bailing and shoring, and every other expense incident to the removal of the material.

Paving and Slope Walls.—Paving, wherever required, will be laid of flat stones set on edge and well rammed, so as to make a good, smooth and close pavement one foot thick, confined at the ends and sides by deep curb stones. Each paving stone shall have a depth of not less than twelve inches.

Wherever required to protect an embankment from the action of water, a pavement or slope wall similar to the foregoing shall be laid on the slope of the embankment, said wall being begun at such depth below the surface of the ground as the Engineer may direct.

Pipe Culverts.—Pipe culverts shall be made of the best quality double strength vitrified clay pipe. Each pipe must be sound and straight, and shall not vary more than half an inch from a true circle. The thickness of twelve-inch pipes shall not be less than one and one-eighth inches; of fifteen-inch pipes not less than one and one-quarter inches; of eighteen-inch pipes not less than one and one-half inches; and of twenty-four-inch pipes not less than two inches.

In laying pipes the trench must be made true to line and grade, the bottom being shaped to exactly fit the lower half of the pipe, with cross trenches to receive the sockets so that each pipe may have a uniform bearing from end to end.

The pipes shall be joined by filing the space between the socket and spigot with a mortar of pure cement without sand. Particular attention must be given to the lower half of the joint where the cement should be pressed into it with the fingers or some tool specially fitted for the purpose. As each joint is

filled, all surplus cement must be carefully removed from the inside of the pipe.

After the pipes are properly laid they must be carefully covered with earth, well rammed, both on the sides and top of the pipe for at least twelve inches in depth.

At the ends of pipes culverts, such parapet or protection walls of brick, stone or concrete shall be built as the Engineer may direct, said walls to be laid in accordance with the foregoing specifications, and paid for by the cubic yard measured in the wall.

Pipe culverts will be paid for by the linear foot measured from end to end of the pipes when laid, the price so paid to cover the whole cost of materials and labor of every kind incident to the completion of the work.

TIMBER TRESTLING.

General Requirements.—All timber structures, including pile and frame trestles, wooden abutments and piers, must be built according to the plans and instructions furnished by the Engineer. The drawings will be to scale, but in all cases dimensions are to be taken from the figures and not by scale. In case any dimensions are omitted, the matter shall be referred to the Engineer. Timber, iron and piles will be paid for in the finished structure, and the prices paid are to cover the cost of materials, tools, scaffolding, excavation, watching and all other items of expense necessary for the execution and maintenance of the work until its final acceptance. No waste of any kind will be paid for except "piles cut off," which will be paid for at the contract price.

The Contractor shall render the Inspector or Pile Recorder any assistance that may be required in the performance of his work.

Piles.—Piles shall be sound and straight sticks of white oak or red cypress, cut from living trees, and shall have all the bark peeled off. Each pile must have at least twelve inches of heart where cut off to receive the cap, and at the smaller end must be not less than nine inches in diameter.

All piles must be properly pointed, or if required, shod with iron shoes, and then driven until they sink not more than five inches under the last five blows of a 2,000 pound hammer, falling twenty-five feet, but a heavier hammer with a shorter fall, equivalent in effect to the foregoing, will be preferred. In driving, the piles must be capped with wrought iron rings, or preferably, with a cup-shaped iron follower, to prevent splitting. Where iron shoes are required, they must be of a kind directed

or approved by the Engineer, and they will be paid for at actual cost to the contractor. All piles injured in driving or driven out of place shall be either cut off or withdrawn, as the Engineer will direct, and another one driven in its stead. The pile thus replaced will not be paid for.

Such grubbing as may be necessary to insure the correct driving of the piles shall be done by the Contractor for the trestling, and will be paid for at a price to be fixed by the Engineer in each case.

The piles under the track stringers must be accurately spaced and driven vertically. The outer piles shall be driven vertically or with a batter, as may be shown by the drawings or directed in each case.

Piles remaining in the structure will be measured and paid for by the linear foot after they are driven and cut off as "Piles Driven," the parts cut off will be measured and paid for by the linear foot as "Piles Cut Off," and the amounts paid for these two items are to cover every expense for labor and materials required in the performance of the work. The pile ends, after they are cut off, are to be the property of the Railway Company, and shall not be removed or used without consent of the Engineer, and then only upon repayment of the contract price.

Parts of the pile heads projecting beyond the caps must be adzed off to a slope of forty-five degrees.

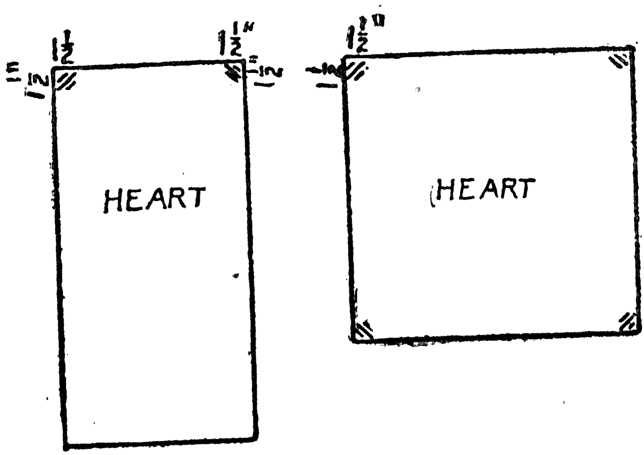
Iron.—The iron bolts used in trestling shall be of the best refined wrought iron, with an ultimate strength of not less than 45,000 pounds per square inch, and an elastic limit of not less than 26,000 pounds.

All bolts shall be perfect in every respect with nuts, heads and screws of the full standard sizes due to their diameters. The thickness of the nut shall not be less than the diameter of the bolt, and the size of its square not less than twice the diameter of the bolt.

Washers and separators shall be of cast iron. They must be smooth, well shaped, free from air holes, cracks, cinders or other imperfections.

Timber and Framing.—All framing timber shall be of white or burr oak, or of white Arkansas or long leaf yellow pine, as shown by the plans and bills of materials. All the timber must be cut from living trees and be free from wanes, black, loose or unsound knots, worm holes, or any kind of decay, as well as from large knots or wind shakes, which impair the strength of the timber, and must be sawed true and of full size. When so indicated on the plans, the timber shall be surfaced.

Sap will be allowed in pine timber as follows: All stringers must show not more than one and one-half inches of



sap on two corners of one of the eight-inch faces. Posts, caps, sills and other large timbers must show not more than one and one-half inches of sap on any one of the four corners. Guard rails must not show more than one inch of sap on one corner only. Sway braces and floor plank must show heart on both faces, and in any cross section be not less than three-fourths heart.

All framing must be done to a close fit and in a thorough and workmanlike manner. No shins or blocking of any kind will be allowed in making joints. Ties and guard rails must be scribed and dapped in place.

Tops and ends of stringers and the bearing surfaces of ties shall be thoroughly painted with a thick coat of pure white lead ground in and mixed with pure linseed oil. This paint shall also be used on both surfaces of the bearing between stringers and caps, caps and posts, posts and sills, sills and piles, or any other joints which may be indicated on the drawings.

Cleaning Up.—After the work is completed the Contractor must remove all staging used in erection, and clean up and burn all shavings, chips and rubbish, and remove all pieces of timber to a sufficient distance from the structure to insure its safety from fire.

Word Engineer Defined.—The word "Engineer," whereever used in this instrument, means the Chief Engineer of the Southern Missouri Railway Company for the time being, or his duly authorized Assistants, or Inspectors, limited by the particular duties entrusted to them. R. M.

172a. Specifications for Building Levees to Confine Flood Waters. The following specification is used (1902) by the State of Louisiana for the building of levees on the banks of the Mississippi river.

The levee shall be built of such material, and disposed and distributed in such manner as the Engineer in charge may direct, under the requirements of the Board of State Engineers. The required allowance for settling shall be added to the height of the levee; this allowance to be at the discretion of the Engineer in charge, up to one-fifth in excess of the net height of the levee; it being understood that a cubic yard of embankment under this agreement is a net cubic yard of settled earth, and equal to five-sixths of a gross cubic yard of loose earth.

The Contractor shall remove all trees, stumps, logs, roots, stalks, weeds, grass, trash and perishable matter of every kind not specially exempted from this requirement by instructions from the Engineer in charge, and plow or spade up the ground over the entire surface to be covered by the embankment. He shall cut muck ditches of such depth and size and in such places as may be prescribed by the Engineer in charge. He shall grub up by the roots all trees and stumps coming within the base of the levee, and three feet on either side of the base. He shall remove all buried logs, brick or walls and other material considered unsuitable by the Engineer in charge. He shall refill all holes made by grubbing or by the removal of unsuitable materials, as aforesaid, with solid earth up to the level of the natural surface; and the filling of such holes shall not be paid for by the cubic yard (except in special cases, when so directed by the Engineer in charge), but shall be a part of the clearing and grubbing to be done as incidental or auxiliary work, the price of which is included in the price per cubic yard hereinafter stipulated. He shall carefully clean all ditches crossing the line of levees, and fill them with solid earth up to the level of the natural surface to a distance of twenty feet from the base of the levee on the land side, where there are no "banquettes," and to the width of the berme on the river side. If required by the

Engineer in charge, the clearing, grubbing, preparation of base and cutting of muck ditch, as above, shall be completed, and the muck ditch refilled throughout the whole length of levee, or any part thereof, before the embankment is begun. He shall cut all trees and stumps within twenty-five feet of the base of the levee on the land side, down to the level of the ground, unless otherwise directed by the Engineer in charge (but shall not disturb or destroy the Engineer's bench marks or other reference points), and shall leave the ground clear of all fallen timber, brush and other debris or material obstructing free passage along the base of the levee on the land side for a width of twenty-five feet. He shall cut down all trees, bushes and saplings for a width of one hundred feet on each side of the levee where it runs through woods, and in open land, shall cut down such trees within one hundred feet of the levee as the Engineer in charge may direct. In the construction of the levee he shall use earth only, except where other material may be ordered by the Engineer in charge, and shall place it in layers of such thickness as may be directed by the Engineer in charge, and extending the full width of the embankment. He shall obtain all earth from the river side of the embankment, except by written permission of the Engineer in charge, leaving a berme of the natural surface ——— feet wide between the barrow pits and the base of the levee. Unless otherwise directed by the Engineer in charge, all barrow pits shall be sloped on the side nearest the embankment, not steeper than three horizontal to one vertical, and on that side shall not be deeper than three feet; and their bottoms shall slope thence uniformly to the side furthest from the embankment, where the depth of the pits shall not exceed six feet. At intervals not greater than three hundred feet "traverses" of the natural surface, not less than twenty feet wide, shall be left undisturbed, extending entirely across the pits, except that a ditch of such width as may be directed by the Engineer in charge shall be cut through the traverses to allow drainage from one part of the pit to another. All existing levees, or parts of old levee, must be left undisturbed except by special permission of the Engineer in charge. He shall cut such openings through the old levee as may be required by the Engineer in charge. He shall dig a drainage ditch on the land side of the levee, if required by the Engineer in charge, of such dimensions and at such distance from the base as may be prescribed, but may not otherwise break up the surface of the ground on the land side of the levee, except by written permission of the Engineer in charge. The earth taken from such openings through the old levee and from drainage ditches shall, when required by the Engineer in charge, be deposited in the

embankment, in which case it shall be paid for as embankment only, but otherwise it shall be measured and paid for in excavation. He shall plant the entire surface of the completed levee with living roots or sods of Bermuda grass not more than one foot apart, and to the satisfaction of the Engineer in charge. He shall take care to preserve the Engineer's stakes and bench marks, and shall at all times keep the station stakes at or opposite their proper stations.

173. Complete Specifications and Contract for Dam No. 5, Southborough, of the Boston Waterworks, July, 1893.

ADVERTISEMENT.

TO CONTRACTORS.

Sealed proposals addressed to the Boston Water Board, and endorsed "Proposals for building Dam No. 5 in the Town of Southborough," will be received by the Boston Water Board, at their office, City Hall, Boston, Mass., until 12 o'clock M., of Monday the seventeenth day of July, 1893, and at that time will be publicly opened and read.

Each bidder must make a personal examination of the location of the dam.

All bids must be made upon blank forms, to be obtained of the City Engineer, Boston, must give the prices proposed, both in writing and in figures, and be signed by the bidder, with his address.

Each bid is to be accompanied by a certified check for two thousand dollars ($2,000), payable to the City of Boston, said check to be returned to the bidder unless he fail to execute the contract, should it be awarded to him.

A bond for one hundred thousand dollars ($100,000) will be required for the faithful performance of the contract, the sureties to be residents of Massachusetts, and satisfactory to said Boston Water Board.

The person or persons to whom the contract may be awarded will be required to appear at this office with the sureties offered by him or them, and execute the contract within six days (not including Sunday) from the date of notification of such award, and the preparation and readiness for signature of the contract; and in case of failure or neglect so to do, he or they will be considered as having abandoned it, and the check accompanying the proposal shall be forfeited to the City of Boston.

All bids will be compared on the basis of the Engineer's estimate of quantities of work to be done, which is as follows:—

(*a*) 14,000 cubic yards soil excavated and placed in spoil-banks.

(*aa*) 13,900 cubic yards soil excavated from spoil-banks and placed on dam.

(*b*) 1,610 square yards sodding.

(*bb*) 5 acres seeding.

(*c*) 230,000 cubic yards earth excavation (trenches, embankments, and backfilling).

(*cc*) 10,000 cubic yards rehandling of excavated materials.

(*d*) 13,400 cubic yards rock excavation.
(*e*) 2,000 feet board measure timber work.
(*ee*) 2,000 feet board measure timber work (tongued and grooved).
(*f*) 800 barrels Portland cement.
(*g*) 14,000 cubic yards concrete masonry.
(*gg*) 800 cubic yards concrete masonry.
(*h*) 9,270 square yards plastering.
(*i*) 256 cubic yards brick masonry.
(*j*) 7500 cubic yards paving. *
(*k*) 10,100 cubic yards riprap.
(*l*) 5,400 cubic yards broken stone.†
(*m*) 22,200 cubic yards rubble-stone masonry.
(*n*) 13,300 square feet facing stone masonry (broken ashlar work).
(*o*) 3,650 cubic yards facing stone masonry (range work).
(*p*) 320 linear feet coping.
(*q*) 290 cubic yards dimension stone masonry.
(*r*) 4,110 square feet hammered work.
(*s*) 1,000 cubic yards masonry laid in American cement mortar 1 to 1, an additional price per cubic yard.
(*t*) 1,000 cubic yards masonry laid in Portland cement mortar 1 to 1, an additional price per cubic yard.
(*u*) 1,000 cubic yards masonry laid in Portland cement mortar 1 to 2, an additional price per cubic yard.
(*v*) 1,000 cubic yards masonry laid in Portland cement mortar 1 to 3, an additional price per cubic yard.
(*w*) 1,575 linear feet of walk.

These quantities are approximate only, and the Boston Water Board expressly reserves the right of increasing or diminishing the same, as may be deemed necessary by its Engineer.

Plans can be seen, and specifications and forms of proposal and contract obtained, at the office of the City Engineer, City Hall, Boston.

The Boston Water Board reserves the right to reject any or all bids, should it deem it to be for the interest of the City of Boston so to do.

ROBERT GRANT,
JOHN W. LEIGHTON,
THOMAS F. DOHERTY,
Boston Water Board.

Office of Boston Water Board,
City Hall, Boston, July 1, 1893.

* 3,200 cubic yards if riprap is used. † 2,800 cubic yards if riprap is used.

PROPOSAL

TO THE BOSTON WATER BOARD FOR BUILDING DAM NO. 5 IN THE TOWN OF SOUTHBOROUGH.

The undersigned hereby declares that he has carefully examined the annexed form of contract and specifications and the drawings therein referred to, and made an inspection of the site of the proposed dam, and will provide all necessary machinery, tools, apparatus, and other means of construction, and do all the work and furnish all the materials called for by said contract and specifications and the requirements under them of the Engineer, for the following sums, to wit:

(*a*) For the removal of soil excavated and placed in spoil banks, including all incidental work, the sum of——— ($——) per cubic yard.

(*aa*) For the removal of soil taken from spoil banks or from other places and placing on the slopes of the embankment, including all incidental work, the sum of——— ($——) per cubic yard.

(*b*) For sodding, including all incidental work, the sum of——— ($——)per superficial square yard.

(*bb*) For seeding, including all incidental work, the sum of——— ($——) per acre.

(*c*) For earth excavation, including its disposal in embankments and refilling, or as otherwise ordered by the engineer, and all incidental work, the sum of——— ($——) per cubic yard.

(*cc*) For rehandling of excavated materials from spoil banks and placing, including all incidental work, the sum of ——— ($——) per cubic yard.

(*d*) For rock excavation, including its disposal and all incidental work, the sum of——— ($——) per cubic yard.

(*e*) For permanent timber work, except tongued and grooved timber, placed, including all incidental work, the sum of——— ($——) per thousand feet B. M.

(*ee*) For permanent timber work, tongued and grooved, placed, including all incidental work, the sum of———($——) per thousand feet B. M.

(*f*) For Portland cement ordered by the engineer, delivered where ordered on the work, in barrels containing 400 pounds, including all incidental work, the sum of——— ($——) per barrel.

(*g*) For concrete masonry, in place, formed of five parts of broken stone or screened gravel, to one part of cement, and made with American cement mortar mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*gg*) For concrete masonry, in place, formed of three parts of broken stone or screened gravel to one part of cement, and made with American cement mortar mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*h*) For plastering all concrete walls with Portland cement, including all incidental work, the sum of——— ($——) per superficial square yard.

(*i*) For brick masonry, laid in Portland cement mortar mixed in the proportion of one part of cement to two parts of sand, and including all pointing, centering, etc., and removing the same, and all incidental work, the sum of——— ($——) per cubic yard.

(*j*) For paving in place, including all incidental work, the sum of——— ($——) per cubic yard.

(*k*) For riprap in place, including all incidental work, the sum of——— ($——) per cubic yard.

(*l*) For broken stone in place (other than that used in making concrete and the walk), including all incidental work, the sum of——— ($——) per cubic yard.

(*m*) For rubble-stone masonry, laid in American cement mortar, mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*n*) For face work of broken ashlar, in addition to the price paid per cubic yard as rubble, including pointing in neat Portland cement, and all incidental work, the sum of——— ($——) per superficial square foot.

(*o*) For facing stone masonry of range stones laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand and pointing in neat Portland cement, including all incidental work, the sum of——— ($——) per cubic yard.

(*p*) For coping laid in place, and pointed in neat Portland cement, including all incidental work, the sum of ——— ($——) per linear or running foot.

(*q*) For dimension stone masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, including pointing in neat Portland cement, centering, etc., and all incidental work, the sum of——— ($——) per cubic yard.

(*r*) For fine hammer dressing (six cut work) the sum of ——— ($——) per superficial square foot.

(*s*) For all kinds of masonry laid in American cement mortar mixed in the proportion of one part of cement to one part of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part

of cement to two parts of sand, the sum of——— ($——) per cubic yard.

(*t*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part of cement to one part of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of ——— ($——) per cubic yard.

(*u*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part of cement to two parts of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of ——— ($——) per cubic yard.

(*v*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part of cement to three parts of sand, in addition to the price per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of——— ($——) per cubic yard.

(*w*) For building walk, including all incidental work, the sum of——— ($——) per linear or running foot.

(*x*) For all extra work done by written order of the Boston Water Board, its actual reasonable cost to the Contractor, as determined by the City Engineer, plus fifteen per cent. of said cost.

Accompanying this proposal is a certified check for two thousand dollars ($2,000), which it is agreed shall become the property of the city of Boston, if, in case this proposal shall be accepted by the Boston Water Board, the undersigned shall fail to execute a contract with said city under the conditions of this proposal within the time provided for by the advertisement for proposals; otherwise said check shall be returned to the undersigned.

No member of the city council, and no person in any office or employment of the city of Boston is directly or indirectly interested in this proposal or in any contract which may be made under it, or in expected profits to arise therefrom; and this proposal is made in good faith without collusion or connection with any other person bidding for the same work.

Name——————

——————

Address——————

CITY OF BOSTON.

BOSTON WATER WORKS.

CONTRACT AND SPECIFICATIONS FOR BUILDING DAM NO. 5, IN THE TOWN OF SOUTHBOROUGH.

This Agreement, made and concluded this ——day of———in the year one thousand eight hundred and ninety-three, between the City of Boston, by its Boston Water Board, of the first part, and——————in the State of—————— of the second part:

Commencement of Work.

A. *Witnesseth*, That for and in consideration of the payments and agreements hereinafter mentioned, to be made and performed by the said party of the first part, and under the penalty expressed in a bond bearing even date with these presents and hereunto annexed, the said party of the second part agrees with the said party of the first part to commence the work herein required to be done, within fourteen days after the signing of this contract and to proceed with the work in such order and at such times, points, and seasons, and with such force as may, from time to time, be directed by the engineer, and at his own proper cost and expense, to do all the work and furnish all the materials called for by this agreement, in the manner and under the conditions hereinafter specified.

Completion of Work.

And the said party of the second part hereby agrees to complete all the work called for under this agreement, in all parts and requirements and in full conformity with the plans and specifications on or before November 1, 1896; provided, however, that the water board shall have the right at their discretion to extend the time for said completion of the work. It is further agreed that the permitting of said party of the second part to go on and finish said work after the time specified for its completion shall not operate as a waiver of any of the rights of said city under this contract.

Referee.

B. To prevent all disputes and litigation it is further agreed, by and between the parties to this contract, that the city engineer of Boston (meaning thereby the individual at any time holding the position or acting in the capacity of the engineer of the Boston Water Board) shall be referee in all cases to determine the amount or the quantity of the work which is to be paid for under this contract, and to

decide all questions* which may arise relative to the fulfillment of this contract on the part of the contractor, and his estimates and decisions shall be final and conclusive; also that said engineer, by himself, or by assistants and inspectors, acting for him, shall inspect the work to be done under this agreement to see that the same is done strictly in accordance with the requirements of the specifications hereinafter set forth.

C. The parties further agree that wherever in this contract the words defined below are used, they shall be understood to have the meanings herein given:

The term "water board" shall mean the Boston Water Board, or any board or committee duly authorized to represent the city of Boston in the execution of the work covered by this contract. Water

The word "engineer" when not further qualified, shall mean the said city engineer or his properly authorized agents, limited by the particular duties entrusted to them. Engineer.

The word "contractor" shall mean the person or persons, co-partnership or corporation, who have entered into this contract as party of the second part, or his or their legal representatives. Contractor.

D. It is further agreed that the quantities of work to be done and materials to be furnished, as given in the accompanying notice to contractors are only for the purpose of comparing the bids offered for the work under the contract on a uniform basis; and it is hereby agreed that the Boston Water Board expressly reserves the right to increase or diminish the above mentioned quantities, or any of them, as may be deemed necessary by the engineer.

E. The plans and specifications are intended to be explanatory of each other; but should any discrepancy appear, or any misunderstanding arise as to the import of anything contained in either, the parties hereto further agree that the explanation and decision of the city engineer shall be final and binding on the contractor; and all directions and explanations required, alluded to, or necessary to complete any of the provisions of this contract and specifications and give them due effect, shall be given by the said engineer. Corrections of errors or omissions in drawings or specifications may be made by the said engineer, when such corrections are necessary for the proper fulfillment of the intention of such drawings or specifications, the effect of such corrections Plans.

* This is not binding. See Art. 18, p. 19.

to date from the time that the said engineer gives due notice thereof to said contractor.

Alterations. F. It is further agreed that the city engineer may make alterations in the line, grade, plan, form, position, dimensions, or material of the work herein contemplated, or of any part thereof, either before or after the commencement of construction. If such alterations diminish the quantity of work to be done, they shall not constitute a claim for damages, or for anticipated profits on the work that may be dispensed with; if they increase the amount of work, such increase shall be paid for according to the quantity actually done, and at the price established for such work under this contract; or in case there is no price established, it shall be paid for at its actual reasonable cost as determined by the city engineer, plus fifteen per cent. of said cost.

SPECIFICATIONS FOR BUILDING DAM NO. 5 OF THE SUDBURY RIVER WORKS.

Plans. G. 1. The contractor is to furnish all the material and do all the work necessary to build a dam on the Stony Brook branch of the Sudbury river near the site of Nichol's Mill, so called, in the town of Southborough, Mass. The dam to be in accordance with plans marked Dam No. 5, dated June 16, 1893, signed by William Jackson, city engineer, and filed in the office of the city engineer, City Hall, Boston. The work will also be built in conformity with these specifications.

These plans show only the general character of the work, and during its progress such working plans will be furnished from time to time by the engineer as he may deem necessary.

Borings. The character of the materials to be met with, as shown on said plans, is the result of such examinations as the city of Boston has been able to make; but no guarantee is made as to the accuracy of the borings or test pits or the representations on the plans.

General Description. 2. The dam is to be built partly of masonry and partly of earth, approximately on the lines shown; but if the character of the materials or circumstances arise which render it advisable to change the location of the dam or to change the plans of the dam the city of Boston expressly reserves the right so to do without payment of damages to the contractor, but

all work actually completed will be paid for as per prices bid for the whole work.

The earth embankments will contain plastered concrete core walls. Water-tight material will be placed next these walls on the water side. The embankments will be protected from wash by linings of riprap or paving. A walk will be built on the top of the dam, and other slopes and surfaces covered with soil as directed. The embankments will be separated from the masonry overfall by heavy wing walls. A gate-house with wells and appurtenances as shown will be built next to the north wing wall. The "masonry portion" of the dam will be about 300 feet in length and will be a solid mass of rubble masonry faced with range stones laid in courses.

Where the rock is of poor quality or for other reasons, it may seem to the engineer to be desirable, the core walls both in the center of the embankments and under the masonry section may be carried down deep into the rock.

3. The work to be done in a general way consists in stripping the site of the dam; building up the embankments in layers, and in paving or otherwise protecting their surfaces; doing all blasting, rock and timber work; constructing all masonry; building in all iron work in connection with brick or other masonry; laying pipes through the dam; doing all pumping or other temporary work in connection with the permanent work, and delivering over to said city of Boston the whole structure in a complete condition with the masonry all pointed and with the dam ready to be put into service in accordance with the plans and these specifications. **Work to be Done.**

All work during its progress and on its completion must conform truly to the lines, grades, and levels to be determined and given hereafter by the engineer, and due facilities and such assistance and materials as he may require must be furnished by the contractor without extra charge, and the engineer's marks must be carefully preserved. The work must also be built in accordance with the plans and directions which shall be given by him from time to time, subject to such modifications and additions as said engineer shall deem necessary during the prosecution of the work, and in no case will any work which may be performed, or any materials furnished in excess of the requirements of this contract or of the plans or **Lines, Grades, Levels, Plans.**

of the specifications, be estimated and paid for, unless such excess shall have been ordered by the water board as hereinafter set forth.

Tools and Implements.

The contractor is to furnish all temporary flumes, all materials and all tools, implements, machinery, and labor necessary or convenient for doing all the work herein contracted for, with safety to life and property in accordance with this contract, and within the time specified herein; he will be required to construct and put in complete working order the work herein specified, and is to perform and construct all the work covered by this agreement; the whole to be done in conformity with the plans and these specifications; and all parts to be done to the satisfaction of the city engineer.

Soil.

4. The soil is to be removed from the grounds where the dam, embankments, and other works are to stand. Wherever directed by the engineer said soil to be hauled and put in spoil banks, to remain until required to be placed over the finished surfaces of slopes or embankments. The quantities of soil removed will be measured in the spoil banks and paid for as stipulated in article Q. item (*a*).

The slopes of the embankment are to be covered with soil taken from the spoil banks; if any additional soil is needed for the work, it shall be obtained and taken from such grounds as may be designated by the engineer, and deposited wherever ordered by him; all soil removed from the spoil banks, or from such grounds as the engineer may designate, shall be measured in excavation. It will be rolled or otherwise compacted, and paid for as stipulated in article Q, item (*aa*).

All surfaces which are required to be afterwards sodded or seeded are to be covered with soil at least twenty-four inches in thickness.

Sodding and Seeding.

5. The embankments of the dam, and such other surfaces as may be designated by the engineer, are to be sodded or seeded with grass seed.

All the surfaces to be sodded or seeded are to be carefully graded and particular care taken to make a true and even bearing for the sods to rest on.

Sods.

The sods to be of good quality of earth covered with heavy grass, sound and healthy, and not less than one foot square, and generally of a uniform thickness of three inches. These sizes may be altered by the engineer during the progress of the work. The sods will be cut with a bevel on all

sides, so that when laid they will lap at the edges; to be properly set so as to have a full bearing on their whole lower surface; to be padded down firm with a spade or wooden bat made suitable for the purpose; each sod is to be pinned with one wooden pin, not less than fifteen inches long, so as to be secured to the ground beneath it, and to be so laid that the upper surface shall conform to the true slope of the bank or ground and to the lines given by the engineer. No lean, poor, or broken sods will be allowed in the work, but on the outside edges of the bank sods may be cut to such size and shape as will make a proper finish to the same. The engineer may alter all the above sizes during the progress of the work.

The sodding that shall have been laid shall be well and carefully sprinkled with water as often as the engineer shall deem necessary.

6. The engineer may specify the kind, quality, and amount of seed to be used on all surfaces ordered to be seeded, and he may also direct the manner of seeding, including rolling and watering. **Seeding.**

EARTH EXCAVATION AND EMBANKMENT.

7. Earth excavation is to be made for the foundations, center walls, etc., and for any grading that may be required either above or below the dam, or for any other work in connection with the dam, structures, or appurtenances which the engineer may order, but no payment will be made for earth or other excavation unless specifically staked out and ordered by the engineer. The price bid for excavation will cover all excavations by the contractor for his own convenience or for temporary or protecting work, none of which will be measured or estimated by the engineer.

8. Earth excavation is to be made in accordance with the lines established by the engineer, and the price herein stipulated for earth excavation—article Q, item (*c*)—is to include the work of clearing and grubbing the ground of all trees, stumps, bushes, and roots, and burning or otherwise disposing of the same; of sheeting and bracing and supporting and maintaining all trenches and pits during and after excavation; of all pumping, ditching and draining; of clearing the excavation of all wood or other objectionable materials, of selecting the materials, and of hauling and of disposing of the exca- **Excavation.**

vated materials in making embankments, in filling, refilling, and wasting; of rolling and watering, and all other labor and expenses incidental to the handling of the excavated materials.

Spoil Banks.

9. Whenever, in the opinion of the engineer, the material excavated from the pits and trenches can not properly be disposed of in embankment or for other work at one hauling, it shall be deposited in spoil banks, and paid for under article Q, item (*c*), and if subsequently ordered to be used in the work, it shall be paid for a second time under article Q, item (*cc*).

Measurement.

10. All earth work paid for under article Q, items (*c*) and (*cc*), shall be measured in excavation.

Embankment.

11. The embankments for the dam shall start from a well prepared base, stepped on sloping ground, and shall be carried up in horizontal layers not exceeding four inches in thickness; every layer to be carefully rolled, either with heavy grooved rollers, or steam rollers, and to be well watered. The earth to be well rammed with heavy rammers at such points as can not be reached by the rollers. Special care shall be required in ramming the earth close to the center wall, which shall always be kept at least two feet higher than the adjoining embankment, unless otherwise permitted. The embankments of the dam shall be kept at an uniform height on both sides of the masonry during construction, and at no time will the down-stream half of the dam be allowed to be higher than the up-stream portion.

At all times the earth embankment must be kept three feet above the "masonry portion" of the dam.

Watering.

12. Ample means shall be provided for watering the banks, and any portion of the embankment to which a layer is being applied shall be so wet, when required, that water will stand on the surface.

The contractor shall furnish at his own cost the necessary steam pumping plant and force-main for forcing water into a tank situated on the side hill, at least fifty feet above the top of the dam when completed. From this tank a three-inch distribution pipe, fitted with gates and hose connections, will lead lengthwise over the dam to supply water wherever it may be needed. If the engineer approves, some other method of equal efficiency for the furnishing of water may be substituted for the above

plant. This work is included in the price to be paid for earth excavation.

Clearing and Grubbing.

13. All the grounds covered by the dam and by the borrow pits shall be cleared of all soil, stones, trees, stumps, or other organic or perishable matter, which shall be deposited at such points as shall be designated. If the borrow pits are, in the opinion of the engineer, sufficiently near the dam, the soil or other useful materials may be removed to the spoil banks and measured, otherwise they will not be measured. Stumps and other vegetable substances shall be burned.

14. The surfaces of embankments shall be dressed smoothly to line and grade to receive the soil or broken stones supporting the paving or riprap.

Quality of Earth.

15. The earth used for the embankments shall be free from perishable material of all kinds, and from stones larger than three inches in diameter, and it shall be of a quality approved by the engineer. The portion of the embankment next to the core-wall on the up-stream side of the dam and the refilling of all trenches will be composed of hard-pan or other fine, compact, or selected material approved by the engineer, who shall decide upon the quality and character of the earth to be used at various places, and it must be selected and placed in accordance with his orders.

Classification.

16. All excavation and disposal in embankments and refilling of earth, hard-pan, and other materials, shall be classified and estimated as earth excavation, and paid for at the price hereinafter stipulated, article Q, item (*c*).

ROCK EXCAVATION.

17. Rock excavation is to include the excavation of all solid rock which can not, in the opinion of the engineer, be removed by picking, and of bowlders of one cubic yard or more in size; the price hereinafter specified—article Q, item (*d*)—to be paid for rock excavation shall include the work of hauling and disposing of the same in spoil banks or other places.

How Measured.

18. Rock excavation shall be measured in excavation, and estimated for payment in accordance with the lines given by the engineer. No excavation outside of these lines will be estimated.

19. Rock is to be excavated for the foundations of the dam, core-walls, and gate-house, and wherever the engineer may order.

Steps. 20. In the wall and pipe trenches and in the foundation for the gate-house or other structures, the rock is to be shaped roughly in steps or other form that may be ordered by the engineer.

The price bid for rock excavation is to include the cost of supporting and maintaining the excavations, of pumping and draining, of disposing of the excavated materials as ordered by the engineer, and all other incidental expenses.

Explosives 21. All rock excavation in the wall trenches and at any other place designated by the engineer is to be made with explosives of a moderate power, under his directions, and not with high explosives. Black powder may be ordered by him to be used in special cases.

22. All rock surface intended for masonry foundation must be freed from all loose pieces, and be firm and solid, and prepared as directed by the engineer.

FOUNDATION WORK.

23. The foundation work for the centre walls of the dam and for other structures is to be extended to such depth and in such a manner as shall be ordered by the engineer. In bad bottom, sheet piling, tonged and grooved, may be ordered to be driven or placed on one or more sides of the work. If the material of excavation is such, in the opinion of the engineer, as to require especial precaution, the trenches for the centre wall and for other structures may be ordered extended to a great depth, beyond the indications of the plans. The position of the bed rock being uncertain, it is impossible to indicate the bottom of the core-wall with accuracy, and it is distinctly understood that the lines for the foundation shown on the plans are not guaranteed by the city to be correct.

PROTECTIVE WORK.

24. The contractor will be required at his own expense to take care of all water which may come down the stream during the progress of the work, and to make good any damage done to the dam from freshets or other action of the water or the elements.

TIMBER.

25. Timber may be ordered used for platforms, for permanent sheet-piling, and for other permanent

uses. It shall be of the sizes and placed in the manner ordered by the engineer.

26. All timber and lumber so used shall be spruce, sound, straight grained, and free from all shakes, loose knots, and other defects that may impair its strength and durability. The price bid for timber shall cover all incidental expenses incurred for labor, or for tools or materials used in placing, securing, and fastening it.

27. No payment shall be made to the contractor for lumber used for bracing, sheeting, scaffolding, and other temporary purposes.

28. All sheeting and other timber work in the trenches and pits shall be removed unless it is ordered left in, in which case such timber shall be paid for as herein stipulated—article Q, item (*e*)—for permanent timber work.

Tongued and Grooved Timber.

29. The timber to be used for sheet-piling in the foundations and other places may be ordered tongued and grooved. Such timber shall be furnished and placed as ordered, and the price hereinafter stipulated—article Q, item (*cc*)—for tongued and grooved timber is to cover the cost of placing, driving, securing, and fastening the same.

MASONRY.

30. All masonry, except where otherwise specified, shall be laid in hydraulic cement mortar, and shall be built of the forms and dimensions shown on the plans, as directed by the engineer from time to time, and the system of bonding ordered by the engineer shall be strictly followed.

31. All beds and joints must be entirely filled with mortar, and the work in all cases shall be well and thoroughly bonded.

Water.

32. Care must be taken that no water shall interfere with the proper laying of masonry in any of its parts.

Pipes.

33. All means used to prevent water from interfering with the work, even to the extent of furnishing and placing pipes for conducting the water away from points where it might cause injury to the work, must be provided by the contractor at his own expense.

34. Under no circumstances will masonry be allowed to be laid in water.

Iron-work.

35. All iron-work, except the sluice-gates, is to be built in the masonry without other compensa-

tion than the price herein stipulated to be paid per cubic yard of masonry. The pipes, special castings and other iron work will be furnished and deliverd by the city on the site of the dam, and must then be carefully protected, handled and laid by the contractor in a thorough manner as directed by the engineer.

Freezing Weather. 36. No masonry is to be built between the 15th of November and the 15th of April, or in freezing weather, except by permission of the engineer.

All masonry to be amply protected from the action of frost during the winter. The contractor will be required to make good any damage resulting from frost on any portion of the work.

Sprinkling. 37. All fresh masonry, if allowed to be built in freezing weather, must be covered and protected in a manner satisfactory to the engineer, and during hot weather all newly-built masonry shall be kept wet by sprinkling water on it with a sprinkling pot until it shall have become hard enough to prevent its drying and cracking, and if necessary canvass coverings must be provided.

Cement. 38. American cement and Portland cement are to be used. The American cement must be in good condition and must be equal in quality to the best Rosendale cement. It must be made by manufacturers of established reputation, must be fresh and very fine ground, and in well-made casks. The Portland cement must be of a brand equal in quality to the best English Portland cement. To insure its good quality, all the cement furnished by the contractor will be subject to inspection and rigorous tests; and if found to be of improper quality, will be branded and must be immediately removed from the work; the character of the tests to be determined by the engineer. The contractor shall, at all times, keep in store at some convenient point in the vicinity of the work, a sufficient quantity of cement to allow ample time for the tests to be made without delay to the work of construction. The engineer shall be notified at once of each delivery of cement. It shall be stored in a tight building, each cask must be raised several inches above the ground, by blocking or otherwise.

39. Cement is generally to be used in the form of mortar with an admixture of sand, and when so used, its use is included in the price herein stipulated

for the various kinds of masonry. For the foundation work, however, Portland cement may be ordered by the engineer in exceptionally wet and difficult places, to be used with or without any admixture of sand for grouting seams or for such other purposes as he may direct. The cost of placing said cement will be paid by the city, the price to be paid to be estimated by the engineer unless otherwise stipulated. Such cement is to be paid for per barrel of four hundred pounds, furnished and delivered by the contractor at the place where it must be used. See article Q, item (*f*).

40. All mortar shall be prepared from cement of the quality before described, and clean, sharp sand. These ingredients shall be thoroughly mixed dry, as follows: The proportion of cement ordered, by measure, with the ordered proportion of sand, also by measure; and a moderate dose of water is to be afterwards added to produce a paste of proper consistency; the whole to be thoroughly worked with hoes or other tools. In measuring cement it shall be packed as received in casks from the manufacturer. The mortar shall be freshly mixed for the work in hand, in proper boxes made for the purpose; no mortar to be used that has become hard or set. If the mortar ingredients are mixed at some distance from the work, water shall not be added until the mortar has been brought to the dam and is ready for use. **Mortar.**

41. The price herein stipulated for the various kinds of masonry is contingent on the use of a mortar made of a mixture of one part in a volume of American cement to two parts of sand. Additional prices are herein stipulated for the use of mortars formed with a different mixture of cement and sand. Article Q, items (*s*), (*t*), (*u*), (*v*).

42. The concrete shall be formed of sound broken stones or screened gravel stones not exceeding two inches at their greatest diameter. All stones in any way larger are to be thrown out. The materials to be cleaned from dirt and dust before being used; to be mixed in proper boxes, with mortar of the quality before described, in the proportion of five parts of broken stone to one part of cement; to be laid immediately after mixing, and to be thoroughly compacted throughout the mass by ramming till the water flushes to the surface; the amount of water used for making the concrete to be approved or **Concrete.**

directed by the engineer. The concrete shall be allowed to set for twelve hours, or more, if so directed, before any work shall be laid upon it; and no walking over or working upon it shall be allowed while it is setting. Article Q, item (*g*).

43. Whenever ordered by the engineer the concrete shall be formed of broken stone not exceeding one inch at their greatest diameter, used in the proportion of three parts of broken stone to one part of cement. Article Q, item (*gg*).

Plastering.

44. The up-stream faces of all core-walls, and such other surfaces as the engineer may direct, will be thoroughly plastered with a half inch coat of Portland cement plastering put on in two portions as follows: Next the concrete a thick coating of Portland cement mortar will be put on, mixed in the proportion of one part of cement to one of sand, rubbed to a uniform surface and left rough; over this will be smoothly spread with trowels a coat of neat Portland cement which shall be thoroughly worked to make a perfectly water-tight surface. All plastering will be measured and paid for by the square yard of superficial surface as per article Q, item (*h*).

45. The bricks shall be of the best quality of hard-burned bricks; burned hard entirely through, regular and uniform in shape and size, and of compact texture. To insure their good quality, the bricks furnished by the contractor will be subject to inspection and rigorous tests, and if found of improper quality will be condemned, the character of the tests to be determined by the engineer. They are to be culled before laying at the expense of the contractor, and all bricks of an improper quality shall be laid aside and removed; the engineer to be furnished with men for this purpose by and at the expense of the contractor.

Brick Masonry.

46. All brick masonry shall be laid with bricks of the quality before described and in Portland cement mortar mixed one part of cement to two of sand. No "bats" shall be used except in the backing, where a moderate proportion (to be determined by the engineer) may be used, but nothing smaller than "half bricks." The bricks to be thoroughly wet just before laying. Every brick to be completely imbedded in mortar under its bottom and on its sides. Care shall be taken to have every joint full of mortar and all joints shall be pointed.

47. All centering shall be made, put up, and removed in a manner satisfactory to the engineer. Centering.

48. All stone masonry is to be built of sound, clean quarry granite stone of quality and size satisfactory to the engineer; all joints to be full of mortar, unless otherwise specified. Stone Masonry.

49. Paving is to be laid without mortar, and is to be used for portions or the whole of the slopes of the dam embankments, and at any other place that may be designated. Paving.

50. This work is to be measured in accordance with the lines shown on the drawings or ordered during the progress of the work. The stones used must be roughly rectangular; all irregular projections and feather edges must be hammered off. No stone will be accepted which has less than the depth represented on the plans or ordered. Each stone used must be set solid on the foundation of broken stone or earth and no interstices must be left.

51. After the slopes which are to receive the paving have been dressed, a layer of broken stone, nine inches thick or less, is to be spread as a foundation for the paving wherever ordered. The broken stone must be sound and hard, not exceeding two inches at the greatest diameter. Broken stones may be used also wherever the engineer may direct, and paid for under this head. Article Q, item (*l*). The cost of the broken stone used for making concrete is included in the price hereinbefore stipulated for concrete laid. Broken Stones.

52. Riprap instead of paving may be used for covering a large portion of the dam slopes, and wherever the engineer may order. It shall be made of stone of such size and quality and in such manner as he shall direct, and must be roughly laid by hand. It will generally be put on in thick layers, and if found cheaper will probably be substituted for paving on the lower slopes of the dam below the berm. Riprap.

53. Rubble-stone masonry is to be used for the central part of the dam, for the wing-walls of the earth embankments, for the gate-house, and wherever ordered by the engineer. Rubble.

It shall be made with sound clean stones of compact texture, free from loose seams and other defects. They must have roughly rectangular forms, and all irregular projections and feather edges must be hammered off before the stones are set. The beds

must be good for materials of this class and must present such even surfaces that when lowering a stone on the surface prepared to receive it, there may be no doubt that the mortar will fill all spaces.

After the bed-joints are thus secured, a moderate quantity of spalls can be used in the preparation of suitable surfaces for receiving other stones. No spalling up under a stone after it is laid will be allowed, neither will any grouting or filling of joints be allowed after the stone is set. Especial care is to be taken to have every stone entirely surrounded by mortar.

The quality of the beds is to regulate, to a large extent, the size of the stones used, as the difficulty of forming a good bed-joint increases with the size of the stones. Various sizes must be used.

Generally the largest stones are not to measure more than twenty cubic feet, and they are to be used in the proportion of about twenty-five per cent. of the whole, but they must be omitted partially or entirely if their beds are not satisfactory. It is expected that one quarter of the stones used will be of such size that two men can handle them. The balance to be composed of intermediate sizes. Regular coursing to be avoided.

Broken Ashlar.

54. The exposed faces of the wing walls, retaining walls, and of any other rubble work that the engineer may designate, are to be made of broken ashlar with joints not exceeding one half inch in thickness; the stones not to be less than 12 inches deep from the face, and to present frequent headers. The joints shall be pointed with neat Portland cement. This face work is to be paid for by the square foot of the superficial area for which it is ordered in addition to the price paid per cubic yard of rubble-stone masonry, but the right is reserved to change this masonry to range work, should it be for the interest of the city so to do. Article Q, item (*n*).

Rangework.

55. The outer faces of the masonry dam, and if found best the gate-chamber and any other masonry that may be designated, are to be made of range stones, as shown on the plans, the stones to be of unobjectionable quality, sound and durable, free from all seams and other defects, and of such kind as shall be approved by the engineer. They shall be pointed with neat Portland cement.

All beds, builds, and joints are to be cut true to a depth of not more than 4 inches, and not less than

3 inches from the faces and to surfaces allowing of one half inch joints at most; the joints for the remaining part of the stones not to exceed 2 inches in thickness at any point.

56. All cut arrises to be true, well defined, and sharp. Arrises.

57. Where this class of masonry joins with dimension stone masonry the courses must correspond, and the joining with arches and other dimension stone masonry must be accurate and workmanlike.

Each course to be composed of two stretchers and one header alternately, the stretchers not less than 3 feet long nor more than 7 feet long. Bond.

58. The rise of the courses may vary from bottom to top from 30 inches to 15 inches in approximate vertical progression, and the width of bed of the stretchers is not to be at any point less than the height nor less than 24 inches. The headers are not to be less than 4 feet in length. Courses.

This class of masonry, including the headers, is to be estimated at 30 inches thick throughout. In no case are the tails of the headers to be estimated. Measurement.

59. The coping of the wing walls will be classed as coping stone masonry. The surfaces will be rough pointed to the circular forms given. The capping stones to the posts will be estimated as dimension stone with hammered surfaces. Coping.

60. The prices herein stipulated for range and broken ashlar stone masonry are to cover the cost of pointing, of cutting chisel drafts at all corners and angles in the work, and of preparing the rock faces; but if any six-cut work is ordered in connection with this class of masonry it shall be paid for at the prices hereinafter stipulated for such work. Article Q, item (*r*). Prices.

61. The face bond must not show less than 12 inches lap unless otherwise permitted.

62. The pointing of the faces of all masonry in the dam, gate-house, and wings to be thoroughly done with neat Portland cement after the structures are completed, every joint to be raked out therefor to a depth of at least 2 inches, and if the engineer is satisfied that the pointing at any place is not properly done it must be taken out and done over again. The cement is to be mixed in small quantities and applied before its first setting. Pointing.

Dimension Stone Masonry. 63. Dimension stone masonry must be made of first-class granite of moderately uniform color, free from all seams, discoloration, and other defects, and satisfactory to the engineer. The stones shall be cut to exact dimensions, and all angles and arrises shall be true, well defined, and sharp. All beds, builds, and joints are to be dressed for the full depth of the stone, to surfaces allowing of one quarter (¼) inch joint at most. No plug-hole of more than 6 inches across or nearer than 3 inches to an arris is to be allowed, and in no case must the aggregate area of the plug-hole in any joint exceed one quarter of its whole area.

The stone shall be laid with one quarter (¼) inch joints, and all face joints shall be pointed with mortar made of neat Portland cement, applied before its first setting. All joints to be raked out to a depth of two inches before pointing; the cost of pointing to be included in the price stipulated for cut stone masonry.

Rock-face. 64. In rock face work the arrises of the stones enclosing the rock face must be pitched to true lines; the face projections to be bold, and from 3 to 5 inches beyond the arrises. The angles of all walls or structures having rock faces are to be defined by a chisel draft not less than 1½ inches wide on each face.

Hammered Work. 65. In fine hammered work the face of the stones must be brought to a true plane and fine dressed, with a hammer having six blades to the inch.

For fine hammer-dressing (six-cut work) the price stipulated in article Q, item (*r*), per superficial square foot of dressing will be paid in addition to the price per cubic yard of masonry.

Grooves. 66. No payment will be made for cutting grooves and recesses other than the price paid for the dressing of their surfaces, which are to be fine hammered.

Walk. 67. The contractor will build a walk upon the top of the earthen embankments. It will be 8 feet wide and 1 foot in depth, composed of broken stone 9 inches in depth and a thin layer of selected screenings and binding gravel (as ordered). The surface will be moistened and rolled with a hand roller as directed. The broken stone screenings and gravel used in this walk will not be included in any other measurement. Payment will be made for the fin-

ished walk according to the number of linear or running feet it may contain.

GENERAL CLAUSES.

68. If any person employed by the contractor on the work should appear to the engineer to be incompetent, or to act in a disorderly or improper manner, he shall be discharged immediately on the requisition of the engineer, and such person shall not be again employed on the work. Incompetent Workmen.

69. Any materials condemned or rejected by the engineer or his representatives may be branded, or otherwise marked, and shall, on demand, be at once removed to a satisfactory distance from the work. Materials Branded.

70. Any unfaithful or imperfect work which may be discovered before the final acceptance of the work shall be corrected immediately, and any unsatisfactory materials delivered shall be rejected on the requirement of the engineer, notwithstanding that they may have been overlooked by the proper inspector. The inspection of the work shall not relieve the contractor of any of his obligations to perform sound work, as herein prescribed; and all work, of whatever kind, which, during its progress and before it is finally accepted, may become damaged from any cause shall be removed, and replaced by good and satisfactory work. Imperfect Work.

71. Whenever the contractor is not present on any part of the work where it may be desired to give directions, orders will be given by the engineer to, and shall be received and obeyed by, the superintendent or foreman who may have charge of the particular work in relation to which the orders are given. Orders Obeyed.

72. In all the operations connected with the work herein specified, all laws or regulations controlling or limiting in any way the actions of those engaged on the works, or affecting the methods of doing the work or materials applied to it, must be respected and strictly complied with; and during the progress of the work the contractor shall provide such precautions as may be necessary to protect life and property. Laws.

73. After the completion of the work the contractor is to remove all temporary structures built by him, and all surplus materials of all kinds from the site of the work, and to leave them in neat condition. Clearing up.

Subletting. H. The contractor agrees that he will give his personal attention to the fulfillment of this contract; and that he will not sublet the aforesaid work, but will keep the same under his control, and that he will not assign, by power of attorney or otherwise, any portion of the said work, unless by and with the previous consent of the water board, to be signified by endorsement on this agreement.

Ways and Means. I. The contractor shall furnish the necessary scaffolding, ways, and all necessary means and conveniences for the transfer of the material to its proper place and for its erection. And it is also to be understood that the city shall not be held responsible for the care or protection of any materials or parts of the work until its final acceptance.

Access. J. It is further agreed that the engineer, or his authorized agent and assistants, shall at all times have access to the work during its progress; and he shall be furnished with every reasonable facility for ascertaining that the work being done is in accordance with the requirements and intention of this contract.

Alteration. K. Should it be found desirable by the water board to make alterations in the form or character of any of the work, the said water board may order such alterations to be made, defining them in writing and drawings, and they shall be made accordingly; *provided*, that in case such changes increase the cost of the work, the contractor shall be fairly remunerated; and in case they shall diminish the cost of the work, proper deduction from the contract price shall be made; the amount to be paid or deducted to be decided by the city engineer.

Extra Work. L. The contractor hereby agrees that he will do such extra work as may be required by the water board for the proper construction or completion of the whole work herein contemplated; that he will make no claims for extra work unless it shall have been done in obedience to a written order from the said water board or their duly authorized agent; that all claims for extra work done in any month shall be filed in writing with the engineer before the fifteenth of the following month; and that, failing to file such claims within the time required, all rights for pay for such extra work shall be forfeited. The price to be paid for all extra work done shall be its actual reasonable cost to the contractor, as determined by the city engineer, plus fifteen per cent.

M. The contractor is to use such appliances for the performance of all the operations connected with the work embraced under this contract as will secure a satisfactory quality of work and a rate of progress which, in the opinion of the engineer, will secure the completion of the work within the time herein specified. If, at any time before the commencement or during the progress of the work, such appliances appear to the engineer to be inefficient or inappropriate for securing the quality of the work required or the said rate of progress, he may order the contractor to increase their efficiency or to improve their character, and the contractor must conform to such order; but the failure of the engineer to demand such increase of efficiency or improvement shall not relieve the contractor from his obligation to secure the quality of work and the rate of progress established in these specifications. Appliances

N. The said contractor further agrees that if the work to be done under this contract shall be abandoned, or if at any time the engineer shall be of the opinion, and shall so certify in writing to the water board, that the said work is unnecessarily or unreasonably delayed, or that the said contractor is willfully violating any of the conditions or agreements of this contract, or is not executing said contract in good faith, or fails to show such progress in the execution of the work as will give reasonable grounds for anticipating its completion within the required time, the said water board shall have power to notify the said contractor to discontinue all work, or any part thereof, under this contract; and thereupon the said contractor shall cease to continue said work, or such part thereof, as the said water board may designate; and the said water board shall thereupon have the right, at their discretion, to contract with other parties for the delivery or completion of all or any part of the work left uncompleted by said contractor, or for the correction of the whole or any part of said work. And in case the expense so incurred by said water board is less than the sum which would have been payable under this contract if the same had been completed by the said contractor, then the said contractor shall be entitled to receive the difference; and in case such expense shall exceed the last said sum, then the contractor shall, on demand, pay the amount of such excess to the said city, on notice from the said water board of the excess so due; but such ex-

cess to be paid by the contractor shall not exceed the amount of the security for the performance of this contract.

O. The said contractor further agrees that the said water board may, if they deem it expedient to do so, retain out of and amounts due to the said contractor sums sufficient to cover any unpaid claims of mechanics or laborers for work or labor performed under this contract; *provided*, that notice in writing of such claims, signed by the claimants, shall have been previously filed in the office of the city clerk.

P. The said contractor further agrees that he will indemnify and save harmless said city from all claims against said city, under chapter one hundred and ninety-one of the Public Statutes of Massachusetts, and any laws passed since the Public Statutes, with reference to liens on buildings and lands, for labor done and materials furnished under this contract, and shall furnish the said water board with satisfactory evidence, when called for by them, that all persons who have done work or furnished materials under this contract, for which the said city may become liable, and all claims from the various departments of the city government, or private corporations, or individuals, for damage of any kind caused by the construction of said work, have been fully paid or satisfactorily secured; and in case such evidence is not furnished, an amount necessary and sufficient to meet the claims of the persons aforesaid shall be retained from any moneys due, or that may become due, the said contractor under this contract, until the liabilities aforesaid shall be fully discharged or satisfactorily secured.

The said contractor further agrees that he will indemnify and save harmless the said city from all suits or actions, of every name and description, brought against the said city for or on account of any injuries or damages received or sustained by any person or persons, by or from the said contractor, his servants or agents, in the construction of said work, or by or in consequence of any negligence in guarding the same, or any improper materials used in its construction, or by or on account of any act or omission of the said contractor or his agents; and the said contractor further agrees that so much of the money due him under and by virtue of this agreement as shall be considered necessary by the said engineer may be retained by the said city

until all such suits or claims for damages as aforesaid shall have been settled, and evidence to that effect furnished to the satisfaction of the said engineer.

Q. And the said contractor further agrees to receive the following prices as full compensation for furnishing all the materials, and for doing all the work contemplated and embraced in this agreement; also, for all loss or damage arising out of the nature of the work aforesaid, or from the action of the elements, or from any unforeseen obstruction or difficulties which may be encountered in the prosecution of the same; and for all risks of every description connected with the work; also, for all expense incurred by or in consequence of the suspension or discontinuance of said work as herein specified, and for well and faithfully completing the work, and the whole thereof, in the manner and according to the plans and specifications, and the requirements of the engineer under them, to wit:

(*a*) For the removal of soil excavated and placed in spoil banks, including all incidental work, the sum of ——— ($———) per cubic yard.

(*aa*) For the removal of soil taken from spoil banks or from other places and placing on the slopes of the embankment, including all incidental work, the sum of ——— ($——) per cubic yard.

(*b*) For sodding, including all incidental work, the sum of ——— ($——) per superficial square yard.

(*bb*) For seeding, including all incidental work, the sum of ——— ($——) per acre.

(*c*) For earth excavation, including its disposal in embankments and refilling, or as otherwise ordered by the engineer, and all incidental work, the sum of——— ($——) per cubic yard.

(*cc*) For rehandling of excavated materials from spoil banks, and placing, including all incidental work, the sum of——— ($——) per cubic yard.

(*d*) For rock excavation, including its disposal, and all incidental work, the sum of——— ($——) per cubic yard.

(*e*) For permanent timber work, except tougued and grooved timber, placed, including all incidental work, the sum of——— ($——) per thousand feet B. M.

(*ee*) For permanent timber work, tongued and grooved, placed, including all incidental work, the sum of——— ($——) per thousand feet B. M.

(*f*) For Portland cement ordered by the engineer, delivered where ordered on the work, in barrels containing four hundred pounds, including all incidental work, the sum of——— ($——) per barrel.

(*g*) For concrete masonry, in place, formed of five parts of broken stone or screened gravel, to one part of cement, and made with American cement mortar mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*gg*) For concrete masonry, in place, formed of three parts of broken stone or screened gravel to one part of cement and made with American cement mortar mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*h*) For plastering all concrete walls with Portland cement, including all incidental work, the sum of——— ($——) per superficial square yard.

(*i*) For brick masonry, laid in Portland cement mortar mixed in the proportion of one part of cement to two parts of sand, and including all pointing, centering, etc., and removing the same, and all incidental work, the sum of ——— ($——) per cubic yard.

(*j*) For paving in place, including all incidental work, the sum of ——— ($——) per cubic yard.

(*k*) For riprap in place, including all incidental work, the sum of ——— ($——) per cubic yard.

(*l*) For broken stone in place (other than that used in making concrete and the walk), including all incidental work, the sum of ——— ($——) per cubic yard.

(*m*) For rubble-stone masonry, laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, including all incidental work, the sum of——— ($——) per cubic yard.

(*n*) For face work of broken ashlar, in addition to the price paid per cubic yard as rubble, including pointing in neat Portland cement, and all

incidental work, the sum of ——— ($——) per superficial square foot.

(*o*) For facing stone masonry of range stones laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand and pointing in neat Portland cement, including all incidental work, the sum of ——— ($——) per cubic yard.

(*p*) For coping laid in place, and pointed in neat Portland cement, including all incidental work, the sum of ——— ($——) per linear or running foot.

(*q*) For dimension stone masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, including pointing in neat Portland cement, centering, etc., and all incidental work, the sum of ——— ($——) per cubic yard.

(*r*) For fine hammer dressing (six-cut work) the sum of ——— ($——) per superficial square foot.

(*s*) For all kinds of masonry laid in American cement mortar mixed in the proportion of one part of cement to one part of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of——— ($——) per cubic yard.

(*t*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part of cement to one part of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of ——— ($——) per cubic yard.

(*u*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part of cement to two parts of sand, in addition to the prices per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of ——— ($——) per cubic yard.

(*v*) For all kinds of masonry laid in Portland cement mortar mixed in the proportion of one part

of cement to three parts of sand, in addition to the price per cubic yard hereinbefore stipulated to be paid for the same class of masonry laid in American cement mortar mixed in the proportion of one part of cement to two parts of sand, the sum of ——— ($——) per cubic yard.

(*w*) For building walk, including all incidental work, the sum of ——— ($——) per linear or running foot.

(*x*) For all extra work done by written order of the Boston Water Board, its actual reasonable cost to the contractor, as determined by the engineer, plus fifteen per cent. of said cost.

R. And it is agreed that payment for the work embraced in this contract shall be made in the following manner:

A payment will be made, on or about the first day of each month, of 85 per centum of the value of the work completed in place by the contractor on the fifteenth of the previous month, as estimated by the engineer.

Provided, *however*, that the making of such payment may be deferred from month to month, when, in the opinion of the engineer, the value of work done since the last estimate for payment is less than one thousand dollars.

The said contractor further agrees that he shall not be entitled to demand or receive payment for any portion of the aforesaid work or materials, until said work shall have been completed to the satisfaction of the city engineer, and the said city engineer shall have given his certificate to that effect; whereupon the said city will, within forty days after such completion, and the delivery of such certificate, pay the said contractor the whole amount of money accruing to the said contractor under this contract, excepting such sum or sums as may be lawfully retained by said city.

Provided, that nothing herein contained be construed to affect the right hereby reserved of the said water board to reject the whole or any portion of the aforesaid work, should the said certificate be found or known to be inconsistent with the terms of this agreement, or otherwise improperly given.

S. The parties hereto further agree that this contract shall be in writing, and executed in triplicate, one of which triplicates shall be kept by the said engineer, one to be delivered to the city auditor of

said Boston, and one to the said contractor; that this contract shall be utterly void as to the said city if any person appointed to any office, or employed by virtue of any ordinance of said city, is either directly or indirectly interested therein.

And the said contractor further agrees that he will execute a bond in the sum of one hundred thousand dollars ($100,000) and with such sureties as shall be approved by the said Boston Water Board, to keep and perform well and truly all the terms and conditions of this contract on his part to be kept and performed and to indemnify and save harmless the said water board as herein stipulated.

T. And it is also to be understood and agreed that, in case of any alterations, so much of this agreement as is not necessarily affected by such alterations shall remain in force upon the parties hereto.

U. And the said contractor hereby further agrees that the payment of the final amount due under this contract and the adjustment and payment of the bill rendered for work done in accordance with any alterations of the same, shall release the city from any and all claims or liability on account of work performed under said contract or any alteration thereof.

In Witness Whereof, the parties to these presents have hereunto set their hands the year and day first above written.

The City of Boston, by its Boston Water Board. ....
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....
....

SIGNED in the presence of

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....

Know all Men by these Presents,

That we——————————————————
are held and firmly bound unto the CITY OF BOSTON, in the sum of——————————————
dollars, to be paid to the CITY OF BOSTON, or

its certain attorney, its successors and assigns, for which payment, well and truly to be made, we bind ourselves, our heirs, executors, and administrators, jointly and severally, firmly by these presents.

The Condition of this obligation is such that if the above-bounden——————————— shall well and truly keep and perform all the terms and conditions of the foregoing contract for building Dam No. 5, in the town of Southborough on——— part to be kept and performed, and shall indemnify and save harmless the said CITY OF BOSTON, as therein stipulated, then this obligation shall be of no effect; otherwise it shall remain in full force and virtue.

In Witness Whereof, we hereto set our hands and seals on this———day of————in the year eighteen hundred and ninety-three.

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SIGNED AND SEALED in presence of

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174. SPECIFICATIONS FOR THE STRUCTURAL IRON WORK

OF A

HOTEL BUILDING,

TO BE ERECTED ON THE SOUTHWEST CORNER OF 34TH STREET AND 5TH AVENUE FOR JOHN JACOB ASTOR.

H. J. HARDENBERGH,
Architect,
New York.

PURDY & HENDERSON,
Consulting Engineers,
New York and Chicago.

MAY, 1895.

In order to understand the business relations involved in the following specifications, some explanation of them is necessary.

Messrs. Purdy and Henderson, the consulting engineers, are under contract with Mr. H. J. Hardenbergh, architect, to furnish those parts of the plans and specifications for the building which relate to the iron and steel frame work. They are also under contract with Mr. Downey, the agent of the owner, to prepare all the shop drawings, to supervise the inspection, to superintend the erection of the steel frame work, to check all bills rendered by the contractor for this portion of the work, and, in general, to see that all the contracts relating to this part of the building are faithfully fulfilled. The contract for the iron and steel work was let on a pound basis erected. A separate set of specifications were prepared for the inspection of the work, and also one for the use of the computers and draftsmen in preparing detail plans. It will thus be seen that the consulting engineers are under contract to do a great deal more in this matter than is usually expected of the architect, and much more, therefore, than the architect could afford to pay for, if all this service had to be remunerated out of his professional fees. In the most common practice, the owner checks his own bills, pays the contractor for the shop drawings and divides the remaining portion of this additional service with the architect. Only a small portion of the additional fee paid the engineer by this arrangement is consequently an added expense. It is important that consulting engineers should make contracts with the owner for the additional detail work and supervision as well as with the architect for the preparation of the general plans. This kind of a double connection is desirable and likely to secure the most satisfactory service.

The steel construction described in these specifications is that for a new hotel adjoining The Waldorf on the north, corner 34th street and Fifth avenue, New York city. The building is in plan 350 feet by 100 feet, and is sixteen stories high above the sidewalk, with basement and sub-basement, extending 35 feet below ground. It is the largest steel con-

structed building ever designed, containing over 10,000 tons of structural iron. The exterior of the building is finished with stone to the height of three stories above the sidewalk, and with brick, with terra cotta trimmings, above that line. The construction involves many unusual conditions, such as a ballroom on the second story 100 feet long, and 85 feet wide, with vaulted ceiling reaching to the fifth floor. The floors above this great room, and also the roof, are carried on two trusses extending through four stories, the total load carried by the two being about nine million pounds. The columns in the walls around this ballroom are from 60 to 70 feet in length, and some of them carry over three million pounds each. There is also a large dining room on the first floor, which necessitates the use of very heavy trusses, and difficult and costly work. The spaces between the columns are unusually long, 35 and 40 feet being common, thus requiring an unusual quantity of plate girder work. In several other places in the building, rooms extend through two stories, and the roof on three sides has a Mansard slope fifty feet in height, with large towers on the three street corners. All the details have been worked out with great care, and the business relations of the engineer of construction to both the architect and the owner are considered ideal.

Specifications Explained: These specifications are supplemental to the contract already entered into for the constructural iron and steel work of this building, between ——————, parties of the first part,* and——————, parties of the second part. They are the specifications referred to in the first clause of said contract, and which are to be considered a part of that contract.

These specifications are intended to cover all the structural iron work in said building. They are intended to co-operate with the drawings for the same, both those furnished by the architect and those furnished by the engineers as hereinafter specified, and what is called for by either, is as binding as if called for by both. They are intended to describe and provide

* Mr. Astor's agent, who stands as the party of the first part in these specifications, is Mr. John Downey, and he is so named in various parts of the document.

for a finished piece of work. The contractor will understand that the steel construction herein described is also to be complete in every detail, and in every portion of the work, and all material entering into it is to be first-class, and he will be expected to thoroughly understand the construction and to fully inform himself in regard to any points that he may not clearly understand, for what is herein intended to be described, viz.: The complete and perfect construction of the building is the thing required. When necessary or desirable, he must apply to the architect or the engineers for further details or specifications during construction or before proceeding with his work.

Requirements Outlined: This contractor must furnish and set all the iron and steel shown or referred to in these specifications and called for by the said drawings hereinbefore referred to, and when the erection is completed, he must remove all the materials used in performing the work. He must furnish in all cases the exact sections, weights and kinds of material that are called for, and he must follow exact details, methods and instructions called for by these specifications and said drawings. He must set the iron work as fast as may be considered practical in the judgment of the architect, always keeping at least one story in advance of the masonry. He will be expected to give this work his personal supervision, or have a capable man at all times to take care of it. He must also do all the cutting and fitting that may be required in his work to receive the work of other contractors.

Reference in Case of Dispute: Should any difference of opinion or dispute arise in relation to the meaning of these specifications, or of the said drawings furnished by either the architect or the engineers as hereinafter specified, reference must be made to the engineers, but if their decision is not satisfactory appeal may be made to the architect, whose decision on all such points shall be final and conclusive.

Drawings: The general dimensions, arrangement and sections required for the structural iron work herein specified, are shown on the general structural iron drawings prepared and furnished by the architect, and included in pages ―――――― to ――――――,inclusive.

The sections given are those of the Carnegie Steel Company's manufacture. In general, these drawings are made to scale, but scale dimensions must never be used. These drawings, together with these specifications, are the property of the architect, to whom all copies must be returned on the completion of the work. Detail or shop drawings, including drawings of every part and piece of the work, with all the lists, schedules, indexes, erection plans or other directions necessary for the proper manufacture, finish and erection of the work covered

by these specifications, and the said general drawings prepared by the architect, will be made and furnished by the engineers.

Blue prints of the shop drawings, lists and schedules, as many copies of each as are necessary, but not more than five, will be furnished to the contractor for his use in the manufacture of the material. Another complete set of these prints, together with one complete set of prints of the erection drawings, will be furnished to the contractor for use in erection. One complete set of all the drawings, plans, lists and schedules will be furnished to the inspector. All the above-mentioned prints will be furnished by the engineers, free of expense. Additional prints of any of these drawings may be taken by said contractor or inspector, if desired, at their own expense, but originals taken from the office for that purpose must be promptly returned.

Orders: All materials required to be furnished or work to be done under these specifications or by the said general structural iron drawings, prepared by the architect, will be ordered by the engineers from time to time with the shop drawings, lists, schedules, etc., for the same, as fast as they can be prepared, and the contractor for the structural iron work must order no material and perform no work under these specifications until he has received the said detail drawings, lists and schedules for the same. Bolts or other material used temporarily for erection purposes are not included in this specification.

Extras and Bills: No additional work or material, over and above what is called for by said detail drawings, lists and schedules, prepared and furnished as hereinbefore provided, will be allowed unless ordered by the architect in writing. When said detail drawings, lists and schedules are received by the contractor, they must be immediately examined to determine whether the material and work called for by the same may be properly classified in the price classification contained in the contract hereinbefore referred to, and of which these specifications are considered a part; or, in any supplemental agreement that may be made to said contract. In case either or both may not be properly classified, in said price classification, the engineers must be promptly notified of the fact in writing, and a copy of such notification must also be sent to the architect. If no reply, verbal or written, to such notification is received within three days, a second notification must be sent the same as the first, but, in any case, the work called for by such detailed drawings, lists or schedules must proceed without delay, unless the contractor shall receive written instructions to the contrary from the architect or engineers.

No bill for extra work ordered by the architect as herein provided, or not called for by said drawings, lists or schedules will be approved by the architect unless it is rendered imme-

diately upon the completion and acceptance of said work. All bills for material or work not properly included in the price classification hereinbefore referred to, must be made separate from the bills for work and material properly covered by said price classification. All bills must be made sufficiently in detail to permit of their ready verification. The originals of all bills must be sent to the engineers, Purdy & Henderson, and exact duplicates must, at the same time, be sent to John Downey, parties of the first part in the contract hereinbefore referred to.

Building Laws: This contractor must comply with all municipal or corporation ordinances and the laws and regulations relating to buildings in the city of New York.

Risks: This contractor will be liable and responsible for any damage to life, limb or property that may arise or occur to any party whatever, either from accident or owing to his negligence, or that of his employees during the operations of constructing or completing the works herein specified.

Rubbish: This contractor must remove from the premises all rubbish arising from his operations as the work proceeds and at completion of same.

Signs: No signs of any description will be allowed to be placed on or about the building or premises.

Co-operation and Cleaning Up: This contractor must coöperate with the contractors for the other parts of the building, so that when completed it shall be in accordance with the architect's design and a complete and perfect piece of work. He must arrange and carry on his work in such a way that the other contractors shall not be delayed, subject always to the architect. When his work is finished he must remove from the premises all the tools, apparatus, machinery, scaffolding, and the debris pertaining to his part of the work, and leave the job free from all obstruction.

Kind of Material Required: All material required for the trusses, and all the material required for the flanges of riveted girders must be open hearth steel.

All other material required for riveted members, and the beams and channels used in the floors with their connections, may be made of Bessemer steel, unless in special cases, it shall be otherwise specified.

Pins over five inches in diameter must be of forged steel.

All machine driven rivets must be of steel.

Tie rods, bolts, anchors, lâteral ties and all hand driven rivets must be of wrought iron.

Bearing plates in masonry, bases under columns, separators, brackets under plates, and filler blocks more than 1½ inches thick, must be made of cast iron.

Shoes for trusses and column blocks where required must be made of cast steel.

Character and finish of materials: All the steel used in this building must comply with the following specifications:

	Medium Steel.	Soft Steel.
Maximum ultimate strength in lbs. per sq. in..	68,000	60,000
Minimum ultimate strength in lbs. per sq. in..	60,000	
Minimum elastic limit in lbs. per sq. in........	32,000	30,000
Minimum percentage of elongation in 8 inches..	22%	26%

Test pieces of medium steel must bend cold 180° about a diameter equal to the thickness of the piece without any sign of fracture on the convex side of the bends. Test pieces of soft steel must bend cold 180° flat without any sign of fracture on the convex side of the bend. They must also stand the same bend after being heated to a light cherry red and quenched in water whose temperature is 82° Fahrenheit.

Soft steel must be used for rivets and medium steel for all other material. All steel must have a smooth surface and must be free from all faults or defects of any kind or of any indication of unsoundness. Each piece must be straight, free from wind and of proper section. A variation in weight either way of more than 2 per cent. from that specified shall be cause for rejection.

Eye bars used in trusses must comply with the following specifications in full size tests:

Ultimate strength in lbs. per sq. in. not less than................	58,000
" " " " " " " " more "	66,000
Elastic limit in lbs. per square inch not less than	29,000
Elongation in 2 ft. length of bar nearest fracture.................	15%
Reduction of area	40%

The fracture must take place in the body of the bar and must be generally silky. The mill requirements for material for eye bars must be as specified for by the manufacturers of the bars.

All wrought iron used in this building must have an ultimate strength of not less than 48,000 lbs. per square inch, an elastic limit of not less than 26,000 lbs. per square inch, and an elongation of 20 per cent. in 8 inches. The wrought iron required for bolts and rivets must be so ductile that test pieces will bend cold 180 degrees flat without any sign of fracture on the convex side of the bend. All the wrought iron must be perfectly welded in rolling, fibrous, uniform and free from all defects. Each piece must be straight and of proper section.

All the cast steel used in this building must have an ultimate strength of not less than 60,000 lbs. per square inch, an elastic limit of not less than 32,000 lbs. per square inch, and an elongation in 8 inches of not less than 15 per cent. All castings must be annealed and all test pieces must be cast as coupons and detached after annealing.

All the cast iron used in this building must be tough gray iron, free from cold shuts, blow holes or other serious defects. Its quality must be such that sample bars 1 inch square cast in sand moulds must be capable of sustaining on a clear span of 4½ feet a central load of 500 pounds when tested in the rough bar.

Painting: All iron must receive a coat of pure raw linseed oil at the rolling mills just before being loaded on the cars.

The covered surfaces (surfaces in contact and surfaces enclosed) of all parts of riveted members must receive one good coat of graphite paint, after the pieces are punched and before they are assembled. All finished members must receive one complete coat of the graphite paint before they are taken from the shop or exposed to the weather. All surfaces that can be reached must have one coat of the graphite paint after erection. All truss members must have two coats of paint in the shop and the enclosed surfaces of these members must have the two coats before they are assembled.

Foundation beams and connections must have two coats of paint at the shop. All bolts used in erection and remaining permanently in the building must be dipped in graphite paint before being placed in position.

All pins and bored pin holes or other planed surfaces in the trusses must be coated with white lead and tallow before leaving the shop.

All painting must be done on dry surfaces and preferably warm ones. All dirt and foreign matter of any kind must be removed from the iron before painting. All scale must be removed from finished members before painting the first coat in the shop. All scale must be removed from material required for the trusses before it is oiled at the rolling mill.

The paint used must be the superior graphite paint, prepared and mixed by the Detroit Graphite Manufacturing Company, of Detroit, Michigan.

Inspection: The inspection hereby provided will be made by inspectors employed by John Downey.

The contractor for the structural iron must furnish full and ample means for the inspection of all the materials called for by these specifications, and of all the work required in fitting such materials for erection; and to this end, he shall admit the arch-

itect, engineers, and inspectors to any part of the mills or shops where work under these specifications is being carried on.

To secure proper material, as herein specified, one pulling test must be made from every heat or blow of steel or rolling of iron, and one bending and one quenching test; when such requirements are specified, if these are satisfactory, the whole will be accepted. If they are not satisfactory, others may be made as the inspector may deem expedient. All test pieces must be prepared at the expense of the contractor for the structural iron. The test pieces of rolled steel and wrought iron must be cut out of finished material, and must not be less than ½ square inch in section. They must be at least 10 inches long between fillets when turned down. When possible they must be cut from the full thickness of the section, from which the tests are taken. The method of selecting test pieces for material for eye bars must be as required by the manufacturer of the bars.

The number of test pieces of cast steel must be fixed by the inspector.

Full sized tests of eye bars must be made as required by the architect or engineers. Test bars for such tests will be selected by the inspector from the lot after forging and before boring, the results of the test to determine the acceptance or rejection of the entire number which the test bar represents. Other full sized tests must be made if required.

The material used for all full sized tests will be paid for at cost, less the scrap value of the material to the contractor when the pieces are tested to destruction, and the test proved satisfactory; otherwise it must be solely at the cost of the contractor. The use of testing machines capable of testing both specimens of material and the full sized members, together with all necessary assistance in handling and operating the same, must be furnished by the contractor free of all expense.

All surfaces of all materials must be carefully examined by the inspectors, and all pieces that are of full section—free from flaws—straight and in every way satisfactory, must be accepted. This inspection will not, however, prevent the rejection of any piece at any later time, but before it is riveted in place in the building, if it is discovered that the piece is in any way unsuitable. Ample assistance must be given by this contractor to the inspector in making this examination.

All material manufactured under these specifications must be tested and examined as herein provided before the same is oiled or loaded on the cars for shipment from the mill, and as soon after rolling as may be convenient for the mill, and failure to comply with these specifications will be sufficient cause for the rejection of the material.

The inspection in the shop must, in general, cover the identification of material, the accuracy of work, and fulfillment of specifications and drawings in every respect, and reports of finished weights and progress of the work, in all of which the inspector must have ample opportunity to do his work. All rejected material must be made good to the satisfaction of the inspector.

All long measurements in the shop made by the inspector, must be made with a steel tape which must be compared with the shop's standard measure to assure their agreement.

In case of any disagreement between the inspectors and the contractors regarding the inspection, appeal may be had to Purdy & Henderson, Consulting Engineers, but their decision shall be final.

Beams: In general not more than 1/8 of an inch will be allowed by the drawings for clearance at each end of beams connecting to beams and not more than 1/4 of an inch at each end of beams connecting to columns. All beams supported by connection angles riveted to the webs when finished, must measure out to out of such connection angles, not more than the length given on the drawings, and not more than 1/8 of an inch less than that length. All beams connecting to columns may be 1/2 inch shorter than shown on the drawings, but must not be longer.

All open holes must be true to the drawings, and an error in the distance from end to end, between the open holes in the flanges at the ends of beams of more than 1-16 of an inch must not be approved by the inspector.

Where connections are marked standard, the standards adopted for this particular job must be used. Beams or other material used in floor construction, excepting bent plates used in connections, must not be heated for bending, cutting, or fitting, unless so marked on the drawings.

Beams split or permanently injured by work in the shop must not be used.

Beams which are required to be bolted together with separators in the building, must be assembled and bolted together in shop when practicable.

Columns: The distance from the center of the columns out to the open holes required for the connection of beams, must be verified by the inspector. If, on account of the material overrunning in weight or on any other account, these distances are wrong more than 1-16 of an inch, the error must be remedied, as the inspector may desire.

All columns must be milled or ground at each end to a smooth bearing surface at right angles to the axis of the column, and the inspector must verify from time to time, the adjustment of the machinery used in this work.

All columns must be exactly true to length, and any discrepancies in such lengths of more than 1-32 of an inch, must be reported promptly to the engineers. If more than 1-32 of an inch too long, they must be milled shorter.

Where columns coming over each other are designed to have the same exterior dimensions, a filler about 1-32 of an inch thick must be put under the splice plates where they are riveted to the columns. These fillers must cover the entire area covered by the splice plates. They will not be drawn on the drawings, but will be noted in the bill of material on each drawing where required.

Columns must all be straight and out of wind.

Riveted Girders: Web plates must be arranged so as not to project above or below the flange angles. The lines showing the edges of such plates will be omitted from the drawings.

In general, all stiffener angles must fit tight at both ends.

Open holes in flanges must have the same accuracy required for beams.

All riveted girders must be out of wind before leaving the shop.

Trusses: Eye bars must be entirely free from flaws and of full section. The heads must be so proportioned that the bars will break in the body of the original bar and the process of manufacture and the form of the head must be subject to the approval of the engineers. No welding will be allowed in the body of the bars. They must be perfectly straight before boring and the pin holes must be centered through the center line of the bar. The lengths back to back of pin holes must not vary more than $\frac{1}{64}$ of an inch from the figured lengths when the bars are 20 feet long or less; not more than $\frac{1}{32}$ of an inch when more than 20 feet long. Bars which go side by side in the trusses must be so perfectly bored that the pins will pass through the holes at both ends without driving when the bars are placed in a single pile. The holes must not be more than $\frac{1}{32}$ of an inch larger the pins. All eye bars must be annealed.

Compression members must have all butting ends planed smooth and exactly square to the center line of the member, and they must be assembled in the shop for the fitting of the splice plates and to assure perfect contact throughout. Such members must be entirely free from twists or bends and all work must be neatly finished and first-class in every respect. Pin holes must be bored $\frac{1}{32}$ of an inch larger than the pins, exactly perpendicular to a vertical plane passing through the center line of each member, when placed in a position similar to that which it should occupy in the finished structure.

Pins must be turned straight and smooth and to exact size.

Castings: The cast bases required in the column must be planed smooth on top and to exact dimensions. All holes for the bolts connecting to the columns must be drilled also to the exact measurements given, and the holes in the other castings, both steel and iron, must be drilled when so marked. All surfaces marked planed must be planed smooth and true for a perfect bearing as designed.

Rivets: Drifting that is liable to injure the material must not be allowed anywhere in erection.

Shop rivets must be machine driven as far as possible.

Rivet heads must be concentric with the necks of the rivets and all rivets when driven must completely fill the holes and be tight.

Rivets will be used in erection wherever possible.

All rivets must be uniformly heated.

Holes that do not match sufficiently to admit the rivet without drifting, in assembling work in the shop, must be reamed.

All riveting must be done to the satisfaction of the engineers.

Erection: If beams are used in the construction of the foundations, the contractor for the structural iron must put them in position, both as to plan and as to height, using a surveyor's level for the purpose, but the grouting and covering of the beams will be done by the contractor for the masonry.

The outside building lines will be given, but the contractor for the structural iron must determine and fix the interior lines, and each cast base must be set in its exact position, both as to alignment and to height, supported on wooden wedges, before the bedding is run in. The center of each base must be true to the column center, as given on the plans, within $\frac{1}{16}$ of an inch, and its height must be adjusted exactly, using a surveyor's level and referring to a fixed bench mark. Each base must be bedded with a Portland cement grouting, by pouring the same through the center until all the spaces under and inside the base are filled. The cement must be of some imported brand which must be approved by the architect, and the sand must be clean and sharp and fine. The two must be mixed dry in equal quantities in a box—all that is required for one base at one mixing. Enough water must then be added to make the whole just flow under its own weight. The whole operation of mixing and setting must be done as rapidly as possible. After the bases are set their heights will be inspected by the engineers, and if they are found to vary more than $\frac{1}{8}$ of an inch from the correct height they must be taken up and reset.

The use of iron sledges in driving or hammering beams or columns or other structural iron will not be allowed where it

can be avoided. Wooden mauls must be used wherever their use is possible. Care must also be exercised to prevent the material from falling or from being in any way subjected to heavy shocks.

Especial care must be used to keep the columns plumb and in proper line during erection, and they must be plumbed to the satisfaction of the architects and engineers as often as may be desired. In case the columns are not kept plumb the entire work of erection shall stop at the written order of the architect to that effect, and the measures to be employed to remedy the defect must be approved by the architect before the erection proceeds.*

The sections of columns, truss members, beams or girders must nowhere be cut without first obtaining the approval of the engineers.

Every failure of the material to come together properly must be noted and reported daily to the engineers. If any serious difficulty occurs during erection, it must be reported to the engineers before any unexpected measures are used to meet the difficulty.

The plan or scheme for the erection of the trusses, and the material connected to the trusses must be submitted to the engineers, before the iron work is erected above the ground floor, for their approval.

Pilot nuts must be used in entering all pins.

After the truss members are put in position, before they are materially shadowed by temporary flooring or any other construction, and after all surfaces are thoroughly dried by the heat of the sun, they shall be protected by waterproof canvas, tarred paper, or other materials from further exposure to the weather. Such protection to continue until those parts of the building are under the cover of the other construction of the building. Such protection is desired to prevent water from lodging and remaining in the concealed parts of the work. Any inaccuracy in the matching of the holes in the column splices must be removed by reaming and not by drifting.

Temporary timber bracing must be put in the building wherever required by the architect or the engineers.

The entire work of erection must be done to the satisfaction of both the architects and the engineers.

*Probably the worst practice in the erection of architectural iron work is the very common use of shims in the joints between the successive column sections, thus concentrating the loads on the opposite sides of the cross-section. The columns are usually kept plumb in this manner, but the practice is extremely vicious and should not be allowed. If the faces of the ends are properly planed or milled off, and the base plate is set exactly level, it will not be necessary to use shims. The greatest difficulty is in setting the bed plate in a truly horizontal plane. The ordinary carpenter's level is not sufficiently delicate for this purpose. These specifications are not explicit on these points.—AUTHOR.

175. Specifications for the Machinery and Track Construction of an Electric Railway. The following specifications for the machinery for an electric railway were prepared by Mr. B. J. Arnold, consulting electrical engineer of Chicago, for the St. Charles Street Railroad Company, of New Orleans, in 1895.

The specifications for track construction were prepared by Mr. Richard McCulloch, M. E., engineer of various street railroads in St. Louis. Both are thought to be the best of their kind, and are here added in the second edition of this work.

176. Specifications for Engines. The engines that are purchased under these specifications will be erected in complete running order on foundations furnished by the purchaser in the power house of the railroad company, located on the switch of a steam railroad at New Orleans, La. In General.

Propositions will be considered on each of the following sizes and types of engines: Sizes.

Proposition No. 1. On three 250 horse power self-contained compound condensing tandem or cross engines. Each capable of delivering 250 horse power to its generator, when running at a speed of 150 revolutions per minute at a piston speed of not less than 550 feet nor more than 700 feet per minute, with an initial pressure of 125 pounds per square inch in the steam chest of the high pressure cylinder. The valve motion of each engine to be capable of cutting off automatically from naught to three-quarter stroke.

Each engine to be provided with a cast iron bed plate which shall cover the entire top of the foundations and have a projecting arm or extension of sufficient size to carry the electric generator which may be purchased to be direct-connected to the engine.

The point of cut-off is not specified, but the contractor shall state in his proposition what economy in water consumption he will guarantee his engine to perform when working at the above initial steam pressure and exhausting into a vacuum of 12 pounds below atmosphere, in accordance with the conditions for a test hereinafter mentioned.

By horse power is meant actual power delivered by engine to the generator, and not indicated horse power in the steam cylinders.

Proposition No. 2. On three engines of the same horse power, design, conditions and guarantees, but to run at 250 revolutions per minute.

Proposition No. 3. On three engines of the same design, but built to deliver 200 horse power each to the generator at a speed of 150 revolutions per minute. Same conditions and guarantees as Proposition No. 1.

Proposition No. 4. On three engines of 200 horse power each to run at 250 revolutions per minute. Same design, conditions and guarantees as Proposition No. 1.

Proposition No. 5. On three 250 horse power compound condensing cross or Tandem or releasing valve type of engines, designed to run at a speed of 100 revolutions per minute, to be direct connected to generators, which will be mounted on the engine shaft between out-board bearing and the fly-wheel. Same conditions and guarantees as Proposition No. 1.

Proposition No. 6. On three 250 horse power Corliss or releasing valve engines similar to those called for in Proposition No. 5, but to run at 80 revolutions per minute. Same conditions and guarantees as Proposition No. 1.

Proposition No. 7. Three 200 horse power Corliss or releasing valve type of engines, similar to those called for in Proposition No. 5, but to run at 100 revolutions per minute. Same conditions and guarantees as Proposition No. 1.

Proposition No. 8. Three 200 horse power Corliss or releasing valve type of engine, similar to those called for in Proposition No. 5, but to run at 80 revolutions per minute. Same conditions and guarantees as Proposition No. 1.

Proposition No. 9. On one 500 horse power Tandem compound condensing Corliss or releasing valve type of engine to run at a speed of 80 revolutions per minute, and one 250 horse power Tandem compound condensing Corliss or releasing valve type of engine to run at 80 revolutions per minute. Same conditions and guarantees as Proposition No. 1.

The 500 horse power is to be a center crank engine and so arranged as to carry a generator on each side.

The 250 horse power engine is to be a side crank engine and carries the generator on but one side. The frame, main working parts and low pressure cylinder of this engine shall be designed extra heavy so that high pressure steam can be admitted to the low pressure cylinder, so as to practically double the power of the engine in case of an emergency. Suitable pipe connections and an auxiliary throttle valve will be made to the live steam pipe by the Contractor. The receiver and all receiver connections will also be built strong enough to sustain the extra pressure.

Proposition No. 10. On one 400 horse power Tandem compound condensing Corliss or releasing valve type of engine, designed to run at a speed of 80 revolutions per minute, and one 200 horse power Tandem compound condensing Corliss or releasing valve of engine at 80 revolutions per minute. Same design of engine as called for in Proposition No. 9, and to fulfill the same guarantees as called for in Proposition No. 1.

Cross Compound Engines. The bidders shall also submit figures on cross compound engines under Propositions Nos. 1 and 5.

All engines furnished shall be provided with governing mechanisms which shall be capable of automatically varying the point of cut-off from naught to three-quarter stroke, as the load requires, and of controlling the speed within reasonable limits. The bidder shall state his guarantee on regulation with the engines ranging from half load to full load, and from full load to no load. Regulation.

All Corliss or releasing valve engines shall govern on both high and low pressure cylinders.

All engines furnished will be provided with fly wheels instead of belt or band wheels, and the specifications for each engine shall state the diameter and weight of the wheels which the Contractor proposes to furnish. It should be remembered by the bidder that these engines are designed for electric railway work, and that the fly wheel should be proportioned for such work. Fly Wheels.

The condensers and air pumps will be furnished by the Purchaser but in case the Corliss engines running not over 100 revolutions per minute are purchased, it may be desirable to drive the boiler feed, air and circulating pumps direct from a rock Condensers.

shaft driven from the cranks or cross-heads of the engines, and the bidder will state how much additional will be charged on Propositions 5, 6, 7, 8, 9 and 10 for such addition. He will state in a general way how he proposes to build the pumps.

He will also state how much additional will be charged on each proposition in case he furnishes an independent jet or surface condenser with each engine and all necessary pipe work to connect the condensers with the engines. The steam and water connections to be brought to the condensers by the Purchaser.

Lubricating Devices and Tools.

Each engine will be provided with suitable oil cups or lubricating devices, and each steam cylinder provided with a sight feed cylinder lubricator and one hand pump.

In case of side crank engines the cranks will be provided with a separate floor stand and return oiling tube to be the center of the crank pin.

One complete set of brass oil cans and tray for the same shall be considered a part of each proposition, together with all necessary wrenches, etc., for properly taking care of the engines.

Throttle Valve.

Each engine will be provided with a throttle valve on the high pressure cylinder and have a flange fitted to the exhaust opening, threaded to receive the proper sized exhaust pipe.

Gauges.

Each engine will be provided with a complete set of nickel plated gauges, having 12-inch dials, of the Ashcroft, Crosby or Schaffer & Budenburg manufacture, or others equally as good, consisting of the following:

One Steam Gauge.
One Vacuum Gauge.
One Compound Receiver Gauge.

Safety Valve.

Each receiver shall be provided with an automatic safety valve which will relieve the receiver of extra pressure.

Indicator.

Each proposition shall include one Crosby, Tabor or Thompson steam engine indicator.

Foundation Bolts.

The Contractor will furnish a complete set of foundation bolts with nuts and washers for each engine. These bolts to be delivered at the power house site within thirty days from the date of the awarding of the contract.

Test.

The engines to be tested as follows. First on a constant load at their rated capacity. Second, in actual practice on electric railroad work.

The Contractor in making his guarantee will base it upon the constant load basis when the engine is delivering its full rated power, but he will also state what economy can be obtained from his engine when working on a variable load such as electric railroad work.

In case it is found impracticable by the Engineer who conducts the test on the engines, to determine accurately the delivered power, it will be taken as 8 per cent less than the indicated horse power of the engines as shown by indicator diagrams, on Tandem engines, and 11 per cent on cross compound engines.

Specifics

The Contractor should submit detail specifications with each proposition which shall state the class of material and workmanship that will enter into the construction of the engine which he proposes to furnish under these specifications.

Drawings.

The Contractor shall furnish to the Consulting Engineer of the Purchaser complete set of blue prints within two weeks from the date of the awarding of the contract, of each engine, giving all necessary information regarding the engines, to enable him to properly lay out the foundations for same.

Inspection.

All the machinery purchased under these specifications will be subject to the inspection and approval of the Purchaser.

Payment.

The above machinery will be paid for as follows:

One quarter cash on arrival of the machinery at the power house side track at New Orleans; one quarter cash on the successful starting of the engines, and the balance within 60 days from said date, provided the requirements have been fulfilled and they have been accepted by the Purchaser.

Time of Completion.

All engines furnished under these specifications shall be erected in complete working order on foundations furnished by the Purchaser, on or before the first day of July, 1895, and it is understood that a forfeiture of $25 per day as liquidated damages shall be deducted from the contract price for each and every day after said date that the engines are unable to operate successfully, it being understood that the Contractor is not to be delayed in erecting or starting the engines by the Purchaser.

B. J. A.

eneral. **177. Specifications for Boilers.** The boilers called for under these specifications will be erected in complete working order on foundations furnished by the Purchaser in the power station building located on a steam railroad side track in New Orleans, La.

Propositions will be considered on the following sizes:

Proposition No. 1. On three boilers capable of developing 250 horse power each on a basis of thirty pounds of water per horse power converted from 100 degrees Fahr. into steam at 70 pounds per square inch.

Proposition No. 2. On three 200 horse power boilers. Same rating and conversion.

All boilers furnished shall be of the horizontal water tube type.

The shells shall be of first quality of low carbon steel of Otis or Shoenberg manufacture, or other equally as good, having a tensile strength of about 60,000 pounds per square inch, and each sheet shall have the maker's name stamped where it will be plainly visible.

All tubes entering into the construction of the boilers shall be of first-class quality, and the bidder shall state what make of tubes he will use.

The successful bidder will be required to replace all tubes that burn out within 90 days from the date of the starting of the boiler, provided it is shown that the boilers were not forced beyond their capacity during the said 90 days.

Each boiler will be provided with one Ashcroft, Crosby, or Schaffer & Budenberg nickel plated steam gauge or other equally as good, which shall have a dial not less than 12 inches in diameter.

One Water Column complete with three gauge cocks and glass water gauge.

The Water Column shall have a quick opening valve in each pipe leading to it so as to shut the steam or water off quickly in case of an accident.

Each boiler shall also be provided with an Ashcroft or other standard pop safety stop valve, and to be provided, if possible, with some form of strainer or purifier where the feed water enters the boilers.

Each set of boilers called for in the above propositions shall be furnished with one complete

set of firing irons and flue blower or cleaner. Asbestos seated blow-off cocks and all other valves which usually accompany boilers, with the exception of steam and feed water connections, will be furnished by the Contractor.

All boilers shall be provided with at least 11½ square feet of heating surface per horse power. Heating Surface.

In case the boilers are so designed as to be set in batteries of three, and be easily accessible for cleaning, they will be set in brick work close together with wall on the outside provided with air space and with fire brick walls between the boilers. In case, however, there are side doors on the boilers, the settings will be so arranged that two of the boilers will be set in one battery and the third one set by itself, but so provided that a fourth boiler can be added in the future without having to change the present setting. Settings.

All outside walls shall be of red pressed brick.

The boiler settings shall be lined throughout with good quality of fire brick extending the entire length of the boiler.

The bridge wall will also be lined with fire brick.

The Contractor will state how much additional will be charged for each boiler in case a mechanical stoker or Hawley Down-Draft Furnace is adopted. He will name the make of stoker which he proposes to furnish.

The boilers shall be designed to carry a working pressure of 140 pounds and shall be tested to 250 hydrostatic pressure. Steam Pressure.

Each proposition will be accompanied by complete detail specifications giving the sizes of the principal parts of the boilers, the grate surface and the number of square feet of heating surface of each boiler. Specifications.

Specifications will also state the quality of material and workmanship that will be furnished and give a detail statement of the attachments that will go with each boiler.

The above boilers will be subject to the inspection and approval of the Purchaser. Inspection.

All of the material called for will be erected in complete working order at New Orleans, La., on or before the first day of July, 1895. It is understood that a forfeiture of $25 per day as liqui- Time.

dated damages will be deducted from the contract price for each and every day after said date that the Purchaser is unable to successfully operate his plant through the boilers not being ready to run, it being understood that the Contractor will not be delayed by the Purchaser.

Payment.

Payments to be made as follows: One quarter cash on delivery of boilers at the power house of the Purchaser; one quarter upon the successful starting of the plant and the balance within 60 days from the date of successful starting, provided the boilers have been accepted by the Purchaser.

B. J. A.

In General.

178. Specifications for Condensers and Pumps. All the machinery furnished under these specifications will be delivered F. O. B., cars at the Power House of the Railroad Company in New Orleans, La., on or before the first day of June, 1895.

Sizes.

Proposals will be received on the following sized condensers:

Proposal No. 1. On one Independent steam driven jet or surface condenser, which shall be capable of condensing the steam from 750 horse power of engines. Said engines to be compound and to receive steam at 125 pounds initial pressure on the high pressure cylinder, and consume 18 pounds of water per horse power per hour. The condenser to be capable of maintaining a vacuum of 27" for 18 hours continuously when working at the above capacity and receiving the circulating or injection water at a temperature of sixty degrees Fahr. with pumps running at a piston speed not exceeding sixty feet per minute.

Proposal No. 2. On three jet or surface condensers having a capacity of 250 horse power each, same design, conditions and guarantees as Proposition No. 1.

Proposal No. 3. On one 500 horse power jet or surface condenser and one 250 horse power jet or surface condenser, same guarantees, conditions, etc., as Proposal No. 1.

Proposal No. 4. On one jet or surface condenser having a capacity of 600 horse power. Same conditions and guarantees as Proposal No. 1.

Proposal No. 5. On one jet or surface condenser having a capacity of 400 horse power

and one of 200 horse power. Same conditions and guarantees as Proposal No. 1.

Proposal No. 6. On three jet or surface condensers having a capacity of 200 horse power each. Same conditions and guarantees as Proposal No. 1.

Pumps.

Propositions will also be received on the following sized Independent steam driven feed pumps.

On two outside packed, single acting, brass plunger boiler feed pumps having a capacity sufficient to deliver 20 gallons of water per minute when supplied with steam under 125 pounds pressure, and delivering water against the same pressure, and running at a piston speed not exceeding 60 feet per minute.

The Contractor will also submit propositions on Duplex pumps.

Specifications.

Each bidder will submit with his proposition complete specifications giving in detail the special construction of his machine and in case of surface condensers will state the number of square feet of cooling surface which will be furnished. He will also state the diameter and stroke of the air and circulating pumps and steam cylinders. Brass or composition piston rods must be furnished for the steam and water ends of both the condensers and boiler feed pumps.

Inspection and Approval

The above machinery will be subject to the inspection and approval of the Purchaser or his duly authorized representative. B. J. A.

179. Specifications for Economizers.

In General

The Economizers furnished under these specifications will be erected in complete running order in brick work furnished by the Contractor, on foundations furnished by the Purchaser in the power house of the railroad company at New Orleans, La., on or before the first day of June, 1895. A side track from a steam railroad will extend to the Power House.

General Design.

The Economizer will be of 500 horse power and placed in a passage way leading from the boilers to the smokestack and will consist of vertical cast iron tubes, arranged in such a manner that their ends can be removed so as to make the interior of the tubes easily accessible for cleaning. Each tube shall have some form of mechanical

the full length of the tube to ---- the series of scrapers shall be , one electric motor or independent ine which shall be furnished by the Con-

The Contractor shall give the length, outside and inside diameters, of the tubes and the number which he proposes to furnish. He will also give the method of casting the pipes, making of joints, and general specifications describing the machine. No tubes will be used which are not cast on end and made of thoroughly first-class quality of fine grey cast iron.

He will state the number of valves and kind which he proposes to furnish with his Economizer. Nothing but bronze seated gate valves shall be used in the steam or water pipes leading to and from the Economizer.

Work. The Purchaser will furnish all pipe work leading to the outlet and inlet of the Economizer, but the Contractor will furnish all other valves and additional piping required.

rantee. The Contractor will state what fuel economy he will guarantee to save over an ordinary boiler setting which has no Economizer, provided the temperature of the gases delivered to the Economizer are as follows:

First. With gases at 450 degrees Fahr.

Second. With gases at 550 degrees Fahr.

Third. What temperature the Economizer will deliver water to the boiler when receiving water at 110 degrees Fahr. with the gases entering the Economizer at 450 degrees Fahr.

Fourth. With gases entering the Economizer at 550 degrees Fahr.

All tubes furnished shall be tested to an hydraulic pressure of 350 pounds per square inch before being shipped from the Company's works, and after the Economizer has been put in operation it will be tested by the Purchaser's Engineer to ascertain whether or not it complies with these specifications.

All material that proves defective within thirty days from the date of the successful starting of the machine, shall be replaced by the Contractor without expense to the Purchaser.

The Contractor shall guarantee to protect the Purchaser from suits for infringements of patents. Suits.

All material furnished under these specifications shall be subject to the inspection and approval of the Purchaser. Inspection and Approval.

B. J. A.

180. Specifications for Electric Generators. The machines that will be purchased under these specifications will be erected in complete running order on foundations furnished by the Purchaser, in the Power House of the St. Charles Street Railroad Company, located on a side track of a steam railroad in New Orleans, La. The exact location of the power house not yet being determined it is impracticable to designate the road on which the track will be located. In General.

Propositions will be considered on each of the following sizes and types of generators: Sizes.

Proposition No. 1. On three 200 kilowatts direct-connected multipolar railway generators, designed to give an electrical output of 400 amperes at 500 volts when running at a speed of 150 revolutions per minute.

These generators will operate at a potential varying from 500 to 550 volts, but the kilowatt rating shall be based on a potential of 500 volts.

Each generator shall be provided with suitable projecting lugs for attaching to the cast-iron base of the engine to which it will be direct-connected.

Means must be provided for slipping the field pieces off the armature side-wise, or by separating the fields in a vertical plane in halves and sliding them away from the armature, or by separating the fields on a horizontal plane so the top piece can be lifted off and suitable removable blocks put between the lower field piece and the engine bed or foundations so that by removing these blocks the field casting can be lowered sufficiently to allow the field coils to be slipped off.

No bearings will be furnished with the generator, as the armature will be carried directly on the engine shaft. The bore of the armature hub will be given by the Purchaser. The generators, however, should have their own brush supporting devices which should be attached to the fields of the machine so as to make it unnecessary to attach the

brush holder brackets to the engine castings. In case the latter is necessary, however, the expense for such attachment will be borne by the Contractor.

Proposition No. 2. On three generators of the same design as called for in proposition No. 1, but to run at 250 revolutions per minute.

Proposition No. 3. On three 200 kilowatt generators of the same design as called for in Proposition No. 1, but to run at a speed of 100 revolutions per minute.

Proposition No. 4. On three 200 kilowatt generators to run at a speed of 80 revolutions per minute. Same design and conditions as Proposition No. 1.

Proposition No. 5. On three generators of the same design, but to have a capacity of 150 kilowatts, and to run at a speed of 150 revolutions per minute.

Proposition No. 6. On three generators of 150 kilowatt capacity each, to run at a speed of 250 revolutions per minute.

Proposition No. 7. On three 150 kilowatt generators similar to those called for under Proposition No. 1, but to run at 100 revolutions per minute.

Proposition No. 8. On three 150 Kilowatt generators similar to those called for under Proposition No. 1, but to run at 80 revolutions per minute.

Efficiency.

The Contractor shall state in each proposition the efficiency his generators will give, and it must be in the form of a guarantee.

By efficiency is meant the result that is obtained by dividing the total energy in kilowatts delivered on the switchboard of the station by the mechanical horse power delivered to the armature of the generator, due allowance being made for the loss in the mains leading from the generator brushes to the switchboard. The power delivered to the armature shall be taken as the indicated horse power in the cylinders of the engine, as measured by the engine indicator, less the indicated power required to drive the engine and generator running light or with no load.

Heating.

The generators shall be capable of giving their full capacity for a period of 18 hours in continuous operation without serious sparking at the brushes, and without raising the temperature of the arma-

ture or field coils more than 72 degrees Fahr. above the surrounding atmosphere.

Regulation.

The machine shall be self-exciting and shall maintain a practically constant voltage with the load varying from half to full load when driven at a uniform speed. They shall be able to run in multiple with each other and divide the load proportionately among them without it being necessary for the attendant to adjust regulating devices.

Station Equipment.

With each generator shall be furnished:

One Main Switch of suitable capacity for the machine.

One Automatic Circuit Breaker.

One Lightning Arrester.

One Weston Illuminated Dial Ammeter reading to 500.

One Field Rheostat.

One Four Point Potential Switch.

And with each complete proposition the following:

One Weston Volt Meter reading from 0 to 650 volts.

One Weston Illuminated Dial shunted station or bus ammeter reading to 2,000 amperes.

Seven feeder panels, each one to have the following instruments upon it:

One Maine Switch to carry 250 amperes.

One Weston Illuminated Dial Ammeter reading 250 amperes.

One Automatic Circuit Breaker, suitable for panel, and such minor details as go to complete the system of the Contractor.

All to be mounted upon marbleized slate panels of suitable size to build into a switchboard. No wood or other combustible material can be used in the construction of these instruments.

Brushes.

Carbon brushes are preferred, and when carbon brushes are used brush holders shall be so designed as to clamp the carbon brush securely and have a practically solid connection to binding post from which the flexible cables lead to switchboard. The object being to prevent heating of the brushes and the electrical loss common to some machines faulty in this respect. Should the type of generator bid upon be such as to necessitate copper brushes the builder of said machine will state fully how such brushes are made and secured.

Templates. The Contractor shall furnish the engine builder, free of cost to the Purchaser, a template for each machine, giving the bore of the armature hub and key-seating for same.

Expert. The Contractor shall furnish a thoroughly competent expert to superintend the erection of the generators, who shall remain in charge of the generators for thirty days after they have started. He shall give all necessary information to such men as may be designated by the Purchaser, to enable them to properly operate the generators during the said thirty day period.

Labor. Contractor will furnish all necessary labor and material for erecting the generators complete ready to operate, and for connecting the generators with the switchboard.

Inspection and Approval. The above machinery will be subject to the inspection of the Purchaser, who shall have the authority to decide whether or not the machinery conforms to these specifications.

Test. An accurate test will be made when the generators are in proper condition to work and it is intended that the guarantee made by the Contractor will be fulfilled.

Payments. Payments will be made as follows: One quarter cash on arival of machinery at the power station site at New Orleans; one quarter on the successful starting of the plant and the balance within sixty days thereafter, provided the generators have been approved and accepted by the Purchaser. It is understood of course that the Contractor will not be delayed in starting his machines by the Purchaser.

Time. The above material to be delivered in running order on or before the first day of July, 1895, and it is understood that the Contractor will forfeit $25 per day as liquidated damages for each and every day after the above date that his work remains incomplete.

Specifications. Each bidder will submit a detailed specification of the machines which he proposes to furnish. It is the intention of the writer of these specifications to draw them broad enough to permit any manufacturer of first-class machinery to bid upon the generators, but if any one is prohibited from bidding by any clause in the specifications, they may submit a proposition pointing out the prohibitive

clause, and their bid, if the machinery is of first-class construction, will be considered. It is understood, however, that the speed here given can not be varied from to any great extent.

B. J. A.

181. Specifications for Electric Motors. The motors that will be purchased under these specifications will be delivered by the Contractor at the factory of the car builder, which will be located in the vicinity of Philadelphia, New York, Cleveland or St. Louis. The cars may be manufactured at some other point than the ones mentioned, but the Contractor will deliver the motors as above specified, provided the cars are built within one hundred miles of one of the above points. In General.

Propositions will be considered on the following: Sizes.

Proposition No. 1. On 40-500 volt constant potential single reduction electric motors having a rated capacity of 25 horse power each, and capable of exerting a horizontal drawbar pull of 1,170 pounds, when running at a speed of eight miles per hour, or a drawbar pull of 625 pounds when running at a speed of fifteen miles per hour.

The average speed of the motors will be between eight and ten miles per hour and the maximum speed about fifteen miles per hour.

Proposition No. 2. On 40-500 volt constant potential single reduction electric motors having a rated capacity of 30 horse power each, and capable of exerting a horizontal drawbar pull of 1,400 pounds when running at a speed of eight miles per hour, or 750 pounds when running at a speed of fifteen miles per hour.

The Contractor shall state what current will be required by the motors at a potential of 500 volts when developing the power indicated above, on a straight, level and clean track. Current.

Each motor furnished shall be of the latest form and design of water-proof motor built by the manufacturer. Type of Motor.

All gearing used in connection with the motors and car axle shall be cut gears. The pinion on the armature to be made of steel and the gear attached to the car axle shall be made of such material as the Contractor sees fit to recommend. Gearing

Auxiliaries.

Each motor will be mounted upon a single car, making a total of forty cars to be equipped with one motor each, and with each motor shall be furnished a complete set of gears for attaching to the car axle. Two controlling stands with suitable rheostats, blow-out devices and other automatic attachments for successful working. One trolley with iron pole and bronze wheel with plumbago bearings. The trolley pole to be provided with suitable base and springs for attaching to the car top. One lightning arrester, one fuse block, two overhead switches for making and breaking the circuit, and all necessary wiring in the car body, and underneath the seats to suitably connect the controller, rheostat and motor for successful operation, and such other special devices as may be necessary to conform to the standard system of the bidder.

Labor.

The Contractor will furnish all necessary labor to mount the motors on the car axles at the works of the car manufacturer. Do all the car wiring (except for lights) necessary to connect the motors to the controllers and rheostats and otherwise equip the car for successful operation.

Heating and Sparking.

The motors shall be capable of performing the work required of them, as given in these specifications in ordinary service, for a period of 18 hours in continuous operation without raising the temperature of the armatures or the field coils to more than 75 degrees Fahr. above the surrounding atmosphere, and shall do their work without excessive sparking at the commutator brushes.

Mounting.

The type of motor considered as standard in these specifications is a single reduction motor geared direct to the car axle, and when this class of motor is used it shall be suspended upon some flexible connection which will relieve the car axle of as much weight as possible, and the Contractor will state in his proposition, so far as practical, the method or special design which he proposes to use in mounting the motors.

In case the manufacturer should furnish single motor geared to both axles under these specifications, the bidder shall state fully the method which will be used in mounting and supporting the motors.

Cars and Trucks.

The car bodies and trucks will be furnished by the Purchaser but the motors are expected to handle

an 18 foot closed car body when fully loaded, and to pull the trailer when necessary on a level track around ordinary curves.

Speed of Armatures.

The bidder will state the number of revolutions per minute that his armature will run when driving a car mounted on 33 in. wheel at a speed of eight miles per hour.

Wheels.

The 33 in. wheels will be used throughout and the motors and gearing are so proportioned as to exert their rated capacity with this diameter of wheel.

Winding.

The Contractor will state the diameter of the wire used in the armature and whether or not the armature is wound with one or more windings through each slot, and if two or more wires are used in such slot, whether or not they are connected in multiple on the commutator strips. He will also give the diameter of the wire used on the field coils.

Delivery.

The Contractor will deliver these motors to the car manufacturer within ninety days from the date of the awarding of the contract, and the motors will be shipped from the factory of the car builder to New Orleans by the car manufacturer, and hauled to the car barn or placed therein by the Purchaser, where suitable pits will be provided for cleaning and repairing the motors.

When the Contractor has received notice from the Purchaser that he is ready to open the road for traffic he (the Contractor) shall send a thoroughly competent expert or electrical engineer to New Orleans to superintend the starting and operation of the motors and give instructions to the employees of the railroad company for a period of thirty days which shall be known as the trial period. All expenses and salary of said expert to be borne by the Contractor.

Trial Period

As soon as the road is ready for operation the Purchaser will open it for traffic and operate the cars thereon for a period of thirty days to determine whether or not the motors will do the work required of them successfully and comply with these specifications. During this period the Purchaser will furnish all necessary employees and power for operating the cars. Said employees to operate the motors in accordance with instructions of the Contractor's expert. It being understood, however, that the motors must make the speed and

do the work called for under these specifications during the said thirty days. All parts of the motors that burn out, break, or otherwise prove defective aside from ordinary wear and tear, during the said thirty days, shall be replaced by the Contractor free of cost to the Purchaser.

Inspection and Approval. The machinery purchased under these specifications will be subject to the inspection and approval of the Purchaser.

Specifications. It is the intention of the writer of these specifications to have them sufficiently broad to allow all manufacturers of first-class machinery to bid under them and if anything in them seems to be prohibitive the bidder will submit his proposition pointing out wherein he can not conform to the specifications. He will also submit detailed specifications giving a list of material which he proposes to furnish. The intention of these specifications being only to definitely state the work that the motors will be required to do. B. J. A.

General Specification.

182. Specifications for the Reconstruction of a Horse Railway Track to be Used as an Electric Railway in a City. The work consists in removing the existing track of the * * * Company in the city of * * * and replacing it with the track described in the following specifications. The track is * * * feet long and will contain * * * plain curves, * * * branches off curves, * * * electric railroad crossings and * * * steam railroad crossings. The Contractor will also be required to lay the tracks in the car-shed and the special work connecting the car-shed tracks with the tracks in the street. He will also furnish and erect the poles, span wires, trolley wire and feeder wire as herein described.

All rails, stringers, and ties taken out of the old track shall belong to the Railroad Company and shall be delivered by the Contractor either at the Railroad Company's yards, or forwarded on board cars to the order of the Railroad Company as the engineer may elect.

All work not enumerated in these specifications necessary for the construction of a first-class track and line shall be performed by the Contractor. All work shall be done under the supervision and to the

satisfaction of the Engineer of the Railroad Company, and instructions as to details given by the Engineer or his representative shall be fully carried out. No bills for extra work will be paid except for extra work done by the written order of the Engineer.

The Contractor shall agree to protect the Railroad Company from the beginning of the construction until the road is accepted by the officers of the Railroad Company from all loss of material by theft and from all damage suits and claims arising from personal injuries or property losses sustained in the construction of the road. The Contractor shall also agree to assume the liability in any suit for infringement of patent, arising out of the material used in the construction of the road or out of the use of any patented process.

The railroad company will secure the necessary permits from the municipality and will make the necessary crossing arrangements with the roads which it intersects. The Contractor, however, must perform all work in accordance with city regulations, and shall carry out any instructions given by the city authorities.

Where it is not herein specified that the material manufactured by a certain company shall be furnished, the Contractor shall name in his bid the manufacturer of the material which he proposes to furnish and wherever possible shall submit samples.

The following drawings may be seen at the office of the Engineer. (1) General map of route, showing location of track and proposed location of poles. (2) Detail drawings of crossings, special work, and car-shed tracks. (3) Drawing showing the length, route, and tapping-in points of feeders.

Material.

The rails shall be standard girder rails, seven inches in height, weighing not less than eighty pounds per yard. These rails shall be delivered in lengths of not less than fifty-five feet. The ties shall be of white oak, sawed six by eight inches in section and eight feet long. Brace tie-plates, fitting and supporting the head of the rail, shall be used. The joints shall be cast-welded, but the Contractor shall supply enough fish plates for use on the rails temporarily as herein described. The trolley wire shall be No. 00 hard drawn copper and the span wire No. 4 soft iron wire covered with weatherproof

insulation. The guy wire shall be No. 6 iron wire covered with the same insulation. The span wire shall have a tensile strength of 2,500 pounds and the guy wire a tensile strength of 1,800 pounds.

The poles shall be thirty feet long and shall be made of steel tubing. Those which are used to support curves and terminals shall be made of eight inch, seven inch, and six inch pipe and shall weigh not less than eight hundred pounds. Poles used only for supporting span wires shall be made of six inch, five inch and four inch pipe and shall not weigh less than five hundred pounds. Poles which carry feed wires shall be made of seven inch, six inch and five inch pipe and shall weigh not less than six hundred and fifty pounds. All poles shall be provided with caps and rings to cover the joints.

All of the material used in the construction of the road not herein enumerated shall be of standard design and subject to the approval of the engineer.

Road-bed. For double track an excavation 18 feet wide and 18 inches deep shall be made, and for single track an excavation 9 feet wide and 18 inches deep. Into this shall be placed 4 inches of crushed rock or gravel and rolled until solid. Clean rock which has been excavated from the street may be used for this purpose.

Ties. The ties shall be spaced 24 inches between centers. A tie shall be placed underneath each joint.

Track-work. The rails shall be laid 4 feet and 10 inches between gauge lines. Where there is double track, the distance between the gauge lines of the inside rails shall be 5 feet and 4 inches. Brace tie plates shall be placed under the rail at each tie and care taken that the brace is firmly against the rail before spiking. The ties shall be securely tamped with crushed rock or gravel until the top of the rail is at the established grade of the street and the track carefully lined and surfaced. Both rails shall be laid level by means of a straight-edge and a level. For lining and surfacing, the rails shall be temporarily connected by fish plates.

Joints. The cast-welded joint shall be used. The joint shall be 14 inches long and the casting shall weigh not less than 120 pounds. The iron used for this purpose shall be soft, grey pig. No scrap shall be used. Immediately before casting the joints, the

rail-ends, 7 inches back of the joint, shall be thoroughly cleaned by emery wheels, sand blast, or some other mechanical process. Care must be taken that the rail ends are in contact and perfectly in line before the joint is cast. Means must be provided for holding the rail in position while the joint is cooling. If there are slight irregularities in the rail surface after the joint is cast, they may be removed by filing the top of the rail, but the Engineer shall have the right to reject any joint which is not in line or which is higher or lower than the rail. Joints so rejected shall be removed by sawing the rail 4 feet on each side of the defective joint. A piece of new rail 8 feet long shall be inserted in this opening and new joints cast on each end of it as described above. The Contractor shall guarantee all cast-welded joints for one year and shall repair, free of charge, any which break in this time. In repairing broken joints, if the opening does not exceed 1 inch, the old joint may be chipped off, a section of rail fitting the opening inserted, and a new joint cast around it, the same precautions as to cleaning and preparing the joint being followed as outlined above. If the opening exceeds 1 inch, the joint must be cut out, a piece of rail 8 feet long inserted and new joints cast upon each end of it.

All joints shall be cast-welded except those in the special work and crossings, and those joints connecting the special work and crossings with the straight track. These joints shall be supplied with six-hole fish plates fitting the section of rail which is used.

Special Work

The special work shall be made of a section of rail which will connect with the rail used on the straight track without the use of combination fish plates. Easement curves as indicated on the drawings shall be used at the ends of all curves where the radius is less than 150 feet. Curves of less radius than 150 feet shall have both rails grooved; those varying in radii from 150 to 400 feet shall have the inside rail grooved; and those of greater radii than 400 feet may be sprung from the rail used on the straight track. Switches, mates, frogs, and crossings shall be provided with hardened steel plates set into the castings to take the wear. The special work shall be laid according to the measusements given on the drawings and shall be made

to line in neatly with the straight track. Wherever necessary the Contractar shall furnish special ties, long enough to support the special work. In laying special work, the directions as given above shall be carried out, except that in laying curves of less than 150 feet radius, the outside rail shall be laid ½ inch higher than the inside rail.

Bonds. The Contractor will not be required to bond the cast-welded joints. All joints not cast-welded shall be bonded with a four naught bond of the * * * type. At crossings and special work, each straight rail shall be connected to the corresponding straight rail on the other side by means of an insulated copper cable of 500,000 c. m. cross-section. The connection between the cable and the rail shall be made by means of a copper terminal, shown on the feeder drawing. The place on the rail where this terminal connects shall be amalgamated and the surface of the terminal shall be amalgamated and coated with an amalgam.

Paving. The paving shall follow the welding of the joints as closely as possible. The road-bed up to the tops of the ties shall be filled with crushed macadam, rammed in place. The space between the tracks of a double track shall be paved with the same material as the street outside the tracks. The space between the rails of the track shall be paved with granite blocks, six inches deep, laid on a bed of sand. The space outside of the rails shall be paved with the same material as the rest of the street. In all cases the city regulations in regard to street paving shall be fully carried out and the work shall be done to the satisfaction of the city authorities. Paving which has been removed for the reconstruction of the track may be replaced by the Contractor, if approved by the Engineer. All old paving material not used shall belong to the Contractor and shall be removed by him. Immediately after the paving is finished the Contractor shall remove all dirt from the street and leave it in a neat condition.

Street to be Kept Open. During the building of the road, the Contractor shall, at his own expense, put in temporary wagon crossings made of ties whenever required by the city authorities. He shall, as far as possible, keep the street open for traffic and shall supply the necessary signal lamps and watchmen.

OVERHEAD CONSTRUCTION.

Poles. Poles supporting the straight line shall be set in a hole 6 feet 6 inches deep and 18 inches in diameter. Poles supporting curves shall be set in a hole 6 feet 6 inches deep and 24 inches in diameter. The space around the poles shall be filled with concrete, composed of 1 part of cement, 2 parts of sand, and 4 parts of crushed rock. In setting poles, the top of the pole shall be given a rake of 8 inches from the vertical. City regulations in regard to setting poles shall be strictly complied with. The sidewalk at the base of the pole must be restored to its original condition. Before erection, poles and cross-arms shall receive one coat of asphalt paint and after erection shall receive another.

Line Work. The trolley wire shall be placed as nearly as possible over the center of the track and shall not be less than 18 or more than 20 feet above the rail. The trolley wire shall be anchored at all curves and crossings. The hangers, strain insulators, feeder yokes, and all other overhead appliances shall be of the manufacture of * * * . The connection between the span wire and the pole shall be through a strain insulator. Strain insulators shall be placed in all guy wires and pull-off wires. All joints in the trolley wire shall be made at suspensions by means of splicing ears. No splicing sleeves shall be used.

Curves. The trolley wire over curves must be so located that the trolley wheel rounds the curve without leaving the wire. Pull-offs must be located as designated by the Engineer. Where necessary, the Contractor shall furnish switches and crossings to be located in the trolley wire at turn-outs.

Crossings. At crossings with other roads, where their consent can be obtained, live crossings will be installed, and cut-outs placed in the trolley wire. Where this consent can not be obtained, the Contractor will install insulated crossings of a design to be approved by the Engineer.

Lightning Arresters. Lightning arresters shall be located along the track, two to each mile. They shall be of the manufacture of * * * and the Engineer shall designate their exact location and the manner in which they shall be connected with the trolley and feeder wires, and the manner in which they shall be grounded.

Section Insulators.

Section insulators of the manufacture of * * * shall be placed in the trolley wire in the positions shown on the map of the route of the road.

Feeders.

Feeders shall be furnished according to the drawing. The cross-arms shall be of iron and of an ornamental design. They shall receive one coat of paint before erection and another after erection. The pins for the straight line shall be of locust, and those supporting feed wire on curves shall be made of steel. The insulators shall have recesses in the top for the support of the feed wire and shall be of the manufacture of * * *. Feed wires shall be pulled up neatly and shall be protected from abrasion by trees or other poles. Each feeder shall be drawn into the power house and left long enough to connect with its proper switch on the feeder board. The Contractor, however, will not be required to make this connection. The Contractor shall also furnish and install the cables for ground feeders, in the location shown on the feeder drawing. The connection between the ground feeder and the rail shall be made by means of a brass terminal, the dimensions of which are shown on the feeder drawing. The surface of the brass terminal shall be amalgamated and the terminal shall be bolted to an amalgamated area on the rail. The Contractor shall leave the ends of ground feeders long enough to connect with the switchboard, but he will not be required to make this connection. The feeder line shall be guyed where necessary as the Engineer may direct.

R. McC.

General specifications.

183. General Specifications for the Track and Overhead Construction for an Electric Railway in a Country Town. This work consists of the laying of * * * feet of single track, containing * * * curves * * * terminals, and * * * diamond turn-outs in the city of * * * . It also includes the laying of the tracks and special work in the car-shed and the erection of the poles, span wires, trolley wires and feeders.

All work shall be done under the supervision and to the satisfaction of the engineer of the railroad company. Instructions as to details given by the engineer or his representative shall be fully carried

out. No bills for extra work will be allowed except for extra work done by the written order of the Engineer.

All work not mentioned in these specifications necessary for the construction of a first-class road shall be performed by the Contractor. He will not be required to work on rainy days, but it is expected that he will push the work to its earliest possible completion.

The Contractor shall agree to protect the railroad company from the beginning of the construction until the road is accepted by the officers of the railroad company, from all loss of material by theft, and from all damage suits and claims arising from personal injuries or property losses sustained in the construction of the road.

In making his bid, the Contractor shall name the manufacturer of the material which he proposes using and wherever possible shall furnish samples.

The following drawings may be seen at the office of the Engineer. (1) General map of route, showing location of track, and proposed location of poles. (2) Profile, showing the necessary grading. (3) Detailed drawings of special work and car-shed tracks. (4) Drawing showing the location and sizes of the feeders.

The rails shall be Tee rails, weighing sixty pounds per yard, of the American Society of Civil Engineers' standard section. The ties shall be of white oak, sawed, 6 by 8 inches in section and 8 feet long. Four-hole angle bars fitting this section of rail are to be used at rail joints. The trolley is to be No. O, hard drawn copper, and the span wire 9-32" galvanized iron cable. The poles are to be of white cedar, neatly trimmed and straight. Those for straight line work shall be 30 feet long with 6 inch tops, and those supporting curves or terminals shall be 30 feet long with 8 inch tops. All other material used in this work shall be of standard design and shall be subject to the approval of the Engineer. Material.

Within the city limits, the top of the rail shall conform to the established grade of the street. Outside of the city limits, the grade shown on the profile will be followed. Where necessary, grade stakes to guide the Contractor will be set by the Engineer. Where the track is either above or Grading.

below the surface of the roadway, the roadway for 4 feet outside the rails shall be graded to slope to the ends of the ties.

Roadbed. For the roadbed, an excavation 9 feet wide and 16 inches deep shall be made. Into this shall be placed 3 inches of crushed rock or gravel and rolled with a heavy roller until solid. In macadam streets, the stone which is taken from the street may be used for this purpose. Where there is a surplus of stone in the street, it shall be moved forward to such point as needed. All surplus dirt shall be hauled away by the Contractor and the street left in a neat condition. After completing the track the roadbed shall be filled with broken stone or gravel to the top of the rails. The material used for this purpose shall be clean and free from dirt.

Ties. The ties shall be spaced 30 inches between centers, except at the joints, where a tie shall be placed directly under the joint, with another tie on each side of it, 8 inches from it.

Track Work. The rails shall be laid 4 feet, 8½ inches between gauge lines, and at turn-outs where there is a double track, the distance between the gauge lines of the inside rails shall be 6 feet. The rails shall be fastened to the ties by two hook head spikes at each point where a rail crosses a tie. The center of the track shall correspond with the center of the street unless otherwise directed. The ties shall be securely tamped until the rail is at the proper grade, and the track shall be carefully lined and surfaced. Both rails shall be laid level by means of a straight edge and a level.

Joints. Wherever possible, joints shall be placed opposite one another. The angle-bars shall first be placed on the joints so that the track may be tamped, lined, and surfaced. After this is completed, the angle-bars shall be removed and the bonds placed in position. All lining and surfacing must be done before the bonds are inserted. After all the bolts in the angle-bars are drawn up as tightly as possible, one man shall strike the head of the bolt with a hammer, while another draws up on the nut with a wrench. This operation shall be repeated with each bolt until the nut can not be turned. The tightening of these bolts shall be the last operation before the track is filled in.

Special work shall be laid according to the measurements given on the drawings and must be made to line in neatly with the straight track. At turn-outs, the Contractor shall furnish special ties, long enough to support the switches, mates, frogs, and curved rails. In laying special work, the directions as already given shall be followed, except that in laying curves, the outside rail shall be laid ¾ inch higher than the inside rail. **Special Work.**

Each joint shall be bonded with a four-naught stranded bond placed beneath the joint plate. The bonds shall be of the * * * or * * * type. The two rails of the track shall be cross-bonded every 300 feet by four-naught bonds of the same type. At turn-outs, the 4 rails shall be cross-bonded twice. If the holes for the bonds are punched at the rail mill, they must be reamed out before the bonds are inserted. **Bonds.**

All cross-walks torn up in the construction of the road shall be replaced by the Contractor as soon as the track is filled. **Cross**

During the building of the road, the Contractor shall at his own expense put in temporary wagon crossings made of ties whenever required by the city authorities. He shall also as far as possible keep the street open for traffic. **Temporary Crossings.**

OVERHEAD CONSTRUCTION.

All poles shall be set 6 feet in the ground. Those which support curves or terminals shall be set in concrete. In straight line work, the poles shall be spaced not more than 115 feet apart. **Poles.**

The trolley wire shall be placed as nearly as possible over the center line of the track. The distance from the rail to the trolley wire shall not be less than 18 feet nor more than 20 feet. The trolley wire shall be anchored at all curves and at all crossings. The connection between the span wire and the trolley wire shall be by means of a hanger of standard design to be approved by the Engineer, and the connection between the hanger and the trolley wire shall be by means of a soldered ear, 15 inches long. All joints in the trolley wire shall be made at suspensions by means of splicing ears. No splicing sleeves shall be used. **Suspensions.**

The trolley wire over curves must be so located that the trolley wheel rounds the curve without leav- **Curves.**

ing the wire. Pull-offs must be located not further apart than 4 feet. Where necessary, the Contractor shall furnish crossings and switches to be located in the trolley wire at turn-outs.

Lightning Arresters. Lightning arresters shall be located along the track not more than 3,000 feet apart. They shall be of a design to be approved by the Engineer, who shall designate their exact location and the manner in which they shall be connected to the feeders and trolley wire. They shall be grounded by means of a No. 6 insulated copper wire, soldered to a copper plate not less than one square foot in area, buried in a bed of wet, crushed charcoal, at least 6 feet deep in the ground.

Feeders. Feeders shall be furnished according to the drawings above enumerated. They shall be drawn into the power house and their ends left long enough to connect with the switchboard. The Contractor, however, will not be required to make this connection. The Contractor will be required to furnish the ground feeders for connecting the rails with the switchboard. He will make the connection with the rails as indicated in the feeder drawing and will leave the ends of these feeders long enough to connect with the switchboard.

R. McC.

184. General Specifications for Steel Highway Bridges and Viaducts.* The following specifications have been adopted for highway bridges and viaducts by the American Bridge Company, they having been drawn by Vice-President C. C. Schneider, member American Society Civil Engineers. They will give structures from 20 to 25 per cent. heavier than those heretofore commonly erected for such purposes. The requirements provide for a most excellent shop practice without greatly increasing the cost, provided the shop is properly equipped with modern machine tools. It will be noted that a class of structures is provided for which is intended to cover all ordinary demands. The tables given at the end of this specification will be found especially valuable in preparing designs.

GENERAL DESCRIPTION.

Classification.

1. Bridges under these specifications are divided into six classes, viz:

Class A.—For city traffic.
Class B.—For suburban or interurban traffic with heavy electric cars.
Class C.—For country roads with light electric cars or heavy highway traffic.
Class D.—For country roads with ordinary highway traffic.
Class E1.—For heavy electric street railways only.
Class E2.—For light electric street railways only.

Material.

2. All structures to be of rolled steel, except the flooring and wheel-guards of Classes A, B, C, E1 and E2, and the stringers, flooring and wheel-guards of Class D, which may be of timber. Cast iron or cast steel will be permitted only in machinery of movable bridges and in special cases for shoes and bearings.

Type of Bridges.

3. The following types of bridges are recommended:

For spans up to 25 feet.—Rolled beams.
For spans from 25 to 40 feet.—Rolled beams or plate girders.
For spans from 40 to 80 feet.—Plate or lattice girders.
For spans from 80 to 140 feet.—Lattice girders.

*For specification for Steel Railroad Bridges, see Art. 185, p 459.

For spans over 140 feet.—Lattice girders or pin connected trusses.

Clearance

4. At an elevation of one foot and over above the roadway, the clear distance between trusses shall be at least 14 inches greater than the width of the roadway between wheel-guards.

5. For Classes A, B, C, E1 and E2 the clear headroom for a width of 6 feet over each track shall not be less than 15 feet, for Class D not less than 12½ feet, above the floor.

6. For bridges carrying electric cars the clear width from the centre of track shall not be less than 6½ feet at a height exceeding 1 foot 6 inches above the top of rails where the tracks are straight.

7. In determining the clearance on curves the extreme length of electric car shall be taken as 45 feet, the width 8 feet, and the distance between centers of trucks as 20 feet, unless otherwise specified.

Spacing of Trusses

8. The width between centers of trusses shall in no case be less than one-twentieth of the span between centres of end pins or shoes.

Handrailing.

9. A strong and suitable handrailing shall be placed at each side of the bridge, except where plate girders serve the same purpose, and be rigidly attached to the superstructure.

Nameplate.

10. Each bridge shall have such name plates suitably inscribed and located, as may be required.

Floor Beams.

11. All floor beams in through bridges shall be riveted to the main girders.

Stringers.

12. Steel stringers shall preferably be riveted to the web of the floor beams.

Wooden joists shall not be less than 3 inches thick, shall be spaced not more than 2½ feet between centres, and shall be dapped over the seat angles or floor beams to exact level. In the latter case they shall lap by each other over the full width of the floor beam, and shall be separated ½ inch for free circulation of air.

Roadway Planks.

13. For single thickness the roadway planks shall not be less than 3 inches thick, nor less than one-twelfth of the distance between stringers, and shall be laid transversely with ¼ inch openings.

14. When an additional wearing surface is specified for the roadway, it shall be 1½ inches thick, and the lower planks, of a minimum thickness of 2½ inches, shall be laid diagonally and with ½ inch openings.

15. Wheel-guards of a cross-section not less than 6 inches by 4 inches on each side of the roadway shall be provided. They shall be blocked up from the floor plank with blocks 2 inches by 6 inches by 12 inches long, not over 5 feet apart centre to centre, held in place by one ¾ inch bolt passing through the centre of each blocking piece and securely fastened to the stringer below. The wheel-guards shall be spliced with half and half joints with 6 inches lap over a blocking piece. **Wheel-guards.**

16. The footwalk planks shall not be less than 2 inches thick nor more than 6 inches wide, spaced with ½ inch openings. **Footwalk Planks.**

17. All plank shall be laid with the heart side down; shall have full and even bearing on and be firmly attached to the stringers.

18. For bridges of Classes A and B a solid floor, consisting of stone, asphalt, etc., on a concrete bed, is recommended. For this case the flooring will consist of buckle-plates or corrugated sections, and the concrete bed shall be at least 3 inches thick for the roadway, and 2 inches thick for the footwalk, over the highest point to be covered, not counting rivet or boltheads. **Solid Floor.**

19. Buckleplates shall not be less than 5-16 inch thick for the roadway and ¼ inch thick for the footwalk. **Buckle Plates.**

20. For solid floor the curb holding the paving and acting as a wheel-guard on each side of the roadway shall be of stone or steel projecting about 6 inches above the finished paving at the gutter. The curb shall be so arranged that it can be removed and replaced when worn or injured. There shall also be a metal edging strip on each side of the footwalks to protect and hold the paving in place. **Curbs.**

21. Provision shall be made for drainage clear of all parts of the metal work. **Drainage.**

22. The floor of bridges of Classes E1 and E2 shall consist of cross-ties not less than 6 inches by 6 inches, spaced with openings not exceeding 6 inches and securely fastened to the stringers by bolts. There shall be guard timbers not less than 6 inches by 6 inches on each side of each track, with their inner faces not less than 9 inches from centre of rail. They shall be notched 1 inch over every tie, and fastened to every fourth tie. **Floor of Class E1 and E2.**

LOADS.

Dead Load. 23. In determining the weight of the structure for the purpose of calculating strains, the weight of timber shall be assumed at 4 pounds per foot B. M., the weight of concrete and asphaltum at 130 pounds, of paving brick at 150 pounds and of granite stone at 160 pounds per cubic foot.

The rails, fastenings, splices and guard timbers of street railway tracks, resting on cross-ties, shall be assumed as weighing 100 pounds per lineal foot of track.

Live Load. 24. The bridges of the different classes shall be designed to carry, in addition to their own weight and that of the floor, a moving load, either uniform or concentrated, or both, as specified below, placed so as to give the greatest strain in each part of the structure.

CLASS A.—*City Bridges.*

For the floor and its supports, on each street car track or on any part of the roadway, a concentrated load of 24 tons on two axles 10 feet centres and 5 feet gauge (assumed to occupy a width of 12 feet), and upon the remaining portion of the floor, including foot walks, a load of 100 pounds per square foot.

For the trusses, for spans up to 100 feet, 1,800 pounds per lineal foot of each car track (assumed to occupy 12 feet in width), and 100 pounds per square foot for the remaining floor surface; for spans of 200 feet and over, 1,200 pounds for each lineal foot of track and 80 pounds per square foot of floor; proportionally for intermediate spans. (See table I.)

CLASS B.—*Suburban or Interurban Bridges.*

For the floor and its supports, on any part of the roadway, a concentrated load of 12 tons on two axles 10 feet centres and 5 feet gauge (assumed to occupy a width of 12 feet), or on each street car track a concentrated load of 24 tons on two axles 10 feet centres; and upon the remaining portion of the floor, including footwalks, a load of 100 pounds per square foot.

For the trusses, for spans up to 100 feet, 1,800 pounds per lineal foot of each car track and 80

pounds per square foot for the remaining floor surface; for spans of 200 feet and over 1,200 pounds for each lineal foot of track and 60 pounds per square foot of floor; proportionally for intermediate spans. (See table I.)

CLASS C.—*Heavy Country Highway Bridges.*

For the floor and its supports, on any part of the roadway, a concentrated load of 12 tons on two axles 10 feet centres and 5 feet gauge (assumed to occupy a width of 12 feet), or on each street car track a concentrated load of 18 tons on two axles 10 feet centres; and upon the remaining portion of the floor, including footwalks, a load of 100 pounds per square foot.

For the trusses, same as for Class B, except load on car tracks for spans up to 100 feet will be 1,200 pounds and for spans of 200 feet and over, 1,000 pounds. (See table I.)

CLASS D.—*Ordinary Country Highway Bridges.*

For the floor and its supports, a load of 80 pounds per square foot of total floor surface or 6 tons on two axles 10 feet centres and 5 feet gauge.

For the trusses, a load of 80 pounds per square foot of total floor surface for spans up to 75 feet; and 55 pounds for spans of 200 feet and over; proportionally for intermediate spans. (See table I.)

CLASS E1.—*Bridges for Heavy Electric Street Railways only.*

For the floor and its supports, on each track a load of 24 tons on two axles 10 feet centres.

For the trusses, a load of 1,800 pounds per lineal foot of each car track for spans up to 100 feet; and a load of 1,200 pounds for spans of 200 feet and over; proportionally for intermediate spans. (See table I.)

CLASS E2.—*Bridges for Light Electric Street Railways only.*

For the floor and its supports, on each track a load of 18 tons on two axles 10 feet centres.

For the trusses, a load of 1,200 pounds per lineal foot of each car track for spans up to 100 feet; and

a load of 1,000 pounds for spans of 200 feet and over; proportionally for intermediate spans. (See table I.)

Impact. 25. To compensate for the effect of impact and vibration, 25 per cent. of the maximum strains resulting from the above mentioned live load shall be added thereto.

Wind Pressure. 26. The wind pressure shall be assumed acting in either direction horizontally:

First. At 30 pounds per square foot on the exposed surface of all trusses and the floor as seen in elevation, in addition to a horizontal live load of 150 pounds per lineal foot of the span moving across the bridge.

Second. At 50 pounds per square foot on the exposed surface of all trusses and the floor system. The greatest result shall be assumed in proportioning the parts.

Momentum of Street Cars. 27. For longitudinal bracing of structures carrying street railroads, the momentum produced by suddenly stopping the train shall be considered; the coefficient of friction of wheels sliding upon the rails being assumed as 0.2.

Centrifugal Force. 28. When the structure carrying a street railroad is on a curve, the additional effects due to the centrifugal force shall be considered.

PROPORTION OF PARTS.

Least Thickness of Materials. 29. No material shall be used less than $\frac{1}{4}$ of an inch thick, except for lining or filling vacant places.

Permissible Tensile Strains. 30. All parts of the structure shall be so proportioned that the sum of the maximum loads, together with the impact, shall not cause the tensile strain to exceed:

On soft steel 15,000 pounds per square inch.

On medium steel 17,000 pounds per square inch.

31. The same limiting unit strains shall also be used for members strained by wind pressure, centrifugal force, or momentum of train, if any.

Net Sections. 32. Net sections must be used in all cases in calculating tension members, and, in deducting rivetholes, they must be taken $\frac{1}{8}$ of an inch larger than the size of the rivets.

33. Pin connected riveted tension members shall have a net section through the pin hole 25 per

cent. in excess of the net section of the body of the member. The net section back of the pin hole shall be at least 0.75 of the net section through the pin hole.

Permissible Compressive Strains.

34. For compression members, these permissible strains of 15,000 and 17,000 pounds per square inch shall be reduced in proportion to the ratio of the length to the least radius of gyration of the section by the following formulæ:

For soft steel, $$p = \frac{15{,}000}{1 + \frac{l^2}{13{,}500r^2}}$$

For medium steel, $$p = \frac{17{,}000}{1 + \frac{l^2}{11{,}000r^2}}$$

where p = permissible working strain per square inch in compression.

l = length of pieces in inches, centre to center of connection.

r = least radius of gyration of the section in inches. (See table V.)

35. No compression member, however, shall have a length exceeding 120 times its least radius of gyration, excepting those for wind bracing, which may have a length not exceeding 140 times the least radius of gyration.

Reversal of Strains.

36. The reversal of strain in members of bridges of Classes A, B, C and D need not to be considered, but the members shall be proportioned for the strain giving the larger section.

For bridges of Classes E1 and E2 members subject to alternate strains of tension and compression in immediate succession (as counter-stresses in web members or chords in continuous trusses) shall be so proportioned that the total sectional area is equal to the sum of areas required for each strain.

Combined Strains.

37. In case the maximum strains due to wind, added to the maximum strains due to vertical loading (including impact), shall exceed the following limits:

On soft steel, 19,000 pounds per square inch.

On medium steel, 21,000 pounds per square inch, properly reduced for compression, addition must be made to such sections until these limits are not exceeded.

The permissible strains for the connections shall be increased proportionately.

38. Should the strains be reversed in any possible case, proper provision must be made for such strains in the opposite direction.

Transverse Loading of Tension or Compression Members.

39. When the floor system rests directly on the top or bottom chord, the latter must be so proportioned that the algebraic sum of the strains per square inch on the outer fibre, resulting from the direct compression or tension, and three fourths of the maximum bending moment (the chord being considered as a beam of one panel length, supported at the ends), shall not exceed the before-mentioned limiting strains in tension or compression, the proper amount of impact being added to each kind of loading.

40. The bending moment at panel points shall be assumed equal to that in the centre, but in opposite direction.

41. All other members which are subject to direct strain in addition to bending moment are to be similarly calculated.

Shearing and Bearing Strains.

42. The shearing strain on rivets, bolts or pins, per square inch of section, shall not exceed 11,000 pounds for soft steel, and 12,000 pounds for medium steel; and the pressure upon the bearing surface of the projected semi-intrados (diameter x thickness) of the rivet, bolt or pin hole, shall not exceed 22,000 pounds per square inch for soft steel, and 24,000 pounds for medium steel. (See table VII.)

Field Connections.

43. In field connections the number of rivets or bolts thus found shall be increased 25 per cent. if driven by hand, but 10 per cent. for rivets driven by power.

Bending Strains on Pins.

44. The bending strain on the extreme fibre of pins shall not exceed 22,000 pounds per square inch for soft steel, and 25,000 per square inch for medium steel, when centres of bearings of the strained members are taken as the points of application of the strains. (See table VI.)

Plate Girders.

45. Plate girders shall be proportioned on the assumption that $\frac{1}{8}$ of the gross area of the web is available as flange area. The compressed flange shall have the same sectional area as the tension flange; but the unsupported length of flange shall not exceed 20 times its width.

46. In calculating shearing strains and bearing strains on web rivets of plate girders, the whole of

the shear acting on the side next the abutment is to be considered as being transferred into the flange angles in a distance equal to the depth of the girder.

47. The shearing strain in web plates shall not exceed 9,000 pounds per square inch for soft steel, and 10,000 pounds per square inch for medium steel.

48. The web shall have stiffeners riveted on both sides, with a close bearing against upper and lower flange angles at the ends and inner edges of bearing plates, and at all points of local and concentrated loads, and also, when the thickness of the web is less than 1-60 of the unsupported distance between flange angles, at points throughout the length of the girder, generally not farther apart than the depth of the full web plate, with a maximum limit of 5 feet.

49. The depth of rolled beams shall in no case be less than 1-30 of the span. **Rolled Beams.**

50. The fibre strain on floor timber from dead and live load without impact shall not exceed 1,200 pounds per square inch on yellow pine and white oak, and 1,000 pounds per square inch on white pine and spruce. **Floor T.**

51. Wherever the live and dead load strains of bridges of classes E1 and E2 are of opposite character, only 70 per cent. of the dead load strain shall be considered as effective in counteracting the live load strain. **Provisions for Future Increase of Live Load of Classes E1 and E2.**

DETAILS OF CONSTRUCTION.

52. All truss bridges shall be given a proper camber. **Camber.**

53. All sections shall preferably be made symmetrical, and the pins placed in the line of the neutral axis. **Symmetrical Sections.**

54. Adjustable members in any parts of structures shall preferably be avoided. **Adjustable Members.**

55. All through spans shall have stiff end vertical suspenders. **Truss Bridges.**

56. The heads of eye-bars shall not be less in strength than the body of the bar. **Eye Bar Heads.**

57. All nuts must be of hexagonal shape. **Nuts.**

58. All lateral and sway bracing shall preferably be made of shapes which can resist compression as well as tension. **Lateral and Sway Bracing.**

Portals. 59. All through spans with top lateral bracing shall have portals at each end of span, connected rigidly to endposts. They shall be as deep as the specified head room will allow, and provision shall be made in the end posts for the bending strain produced by the wind pressure.

Diagonal Bracing. 60. Deck bridges shall have diagonal braces at each panel, of sufficient strength to carry half the maximum strain increment due to wind and centrifugal force, if any.

Gusset Plates. 61. Pony trusses and through plate girders shall be stayed by knee braces or gusset plates at the ends, and at each floor beam or transverse strut.

Temperature. 62. Provision shall be made for a free expansion and contraction of all parts, corresponding to a variation of 150 degrees Fahrenheit in temperature.

Bolsters and Expansion Rollers. 63. All bridges exceeding 100 feet in length shall have hinge bolsters on both ends and at one end nests of turned friction rollers, running between planed surfaces. Rollers will not be less than 3 inches in diameter; and the pressure per lineal inch of roller, including impact, shall not exceed $1200\sqrt{d}$ for steel rollers between steel surfaces (d=diameter of roller in inches).

Friction Plates. 64. For bridges less than 100 feet in length, one end shall be free to move upon smooth surfaces.

Bed Plates. 65. Bed plates shall be so proportioned that the pressure upon masonry (including impact) will not exceed 400 pounds per square inch.

Spacing of Rivets. 66. The pitch of rivets, in the direction of the strain shall never exceed 6 inches, nor 16 times the thickness of the thinnest outside plate connected, and not more than 50 times that thickness at right angles to the strain.

67. At the ends of compression members the pitch shall not exceed four diameters of the rivet, for a length equal to twice the width of the member.

68. The distance from the edge of any piece to the centre of a rivet-hole must not be less than $1\frac{1}{2}$ times the diameter of the rivet, nor exceed 8 times the thickness of the plate; and the distance between centres of rivet-holes shall not be less than 3 diameters of the rivet.

Splices. 69. The butt joints of compression members shall be connected by splices to hold them truly in

position; all other joints in riveted work, whether in tension or compression, must be fully spliced.

Tie Plates. 70. All segments of compression members connected by latticing only, shall have tie plates placed as near the ends as practicable. They shall have a length of not less than the greatest depth or width of the member, and a thickness not less than 1-50 of the distance between the rivets connecting them to the compressed members.

Lacing. 71. Single lattice bars shall have a thickness of not less than 1-40, and double bars connected by a rivet at the intersection of not less than 1-60 of the distance between the rivets connecting them to the member; and their width shall be in accordance with American Bridge Company's standards, generally:

For 15-inch channels, or built sections with $3\frac{1}{2}$ and 4-inch angles.	$2\frac{1}{2}$ inches ($\frac{7}{8}$ inch rivets).
For 12, 10 and 9-inch channels, or built sections with 3-inch angles.	$2\frac{1}{4}$ inches ($\frac{3}{4}$ inch rivets).
For 8- and 7-inch channels, or built sections with $2\frac{1}{2}$ inch angles.	2 inches ($\frac{5}{8}$ inch rivets).
For 6- and 5-inch channels, or built sections with 2-inch angles.	$1\frac{3}{4}$ inches ($\frac{1}{2}$ inch rivets.)

Pin Plates. 72. All pin-holes shall be re-enforced by additional material when necessary, so as not to exceed the allowed pressure on the pins. These re-enforcing plates must contain enough rivets to transfer the proportion of pressure which comes upon them, and at least one plate on each side shall extend not less than 6 inches beyond the edge of the tie plate.

Web Splices. 73. Web plates of girders must be spliced at all joints by a plate on each side of the web, capable of transmitting the full strain through splice rivets.

Flange Plates. 74. The flange plates of all girders must be limited in width so as not to extend beyond the outer lines of rivets connecting them with the angles, more than five inches or more than eight times the thickness of the first plate. Where two or more plates are used on the flanges, they shall either be of equal thickness or shall decrease in thickness outward from the angles.

WORKMANSHIP.

Riveted Work Punching.

75. All riveted work shall be punched accurately with holes 1-16 of an inch larger than the size of the rivet, and when the pieces forming one built member are put together, the holes must be truly opposite; no drifting to distort the metal will be allowed; if the hole must be enlarged to admit the rivet, it must be reamed.

Holes for Field Rivets.

76. All holes for field rivets in floorbeam and stringer connections and splices in tension members, shall be accurately drilled to an iron templet or reamed while the connecting parts are temporarily put together.

Planing and Reaming.

77. In medium steel over $\frac{3}{4}$ of an inch thick, all sheared edges shall be planed, and all holes shall be drilled or reamed to a diameter of $\frac{1}{8}$ of an inch larger than the punched holes, so as to remove all the sheared surface of the metal.

Rivets.

78. The rivet heads must be of approved hemispherical shape, and of a uniform size for the same size rivets throughout the work. They must be full and neatly finished throughout the work and concentric with the rivet hole.

79. All rivets when driven must completely fill the holes, the heads be in full contact with the surface, or countersunk when so required.

Riveters.

80. Wherever possible, all rivets shall be machine driven. Power riveters shall be direct acting machines, worked by steam, hydraulic pressure, or compressed air.

Bolts.

81. When members are connected by bolts which transmit shearing strains, such bolts must have a driving fit.

Neat Finish.

82. The several pieces forming one built member must fit closely together, and when riveted shall be free from twists, bends, or open joints.

83. All portions of the work exposed to view shall be neatly finished.

Contact Surfaces.

84. All surfaces in contact shall be painted before they are put together.

Forged Work Eye-Bars.

85. The heads of eye-bars shall be made by upsetting, rolling, or forging into shape. Welds in the body of the bar will not be allowed.

86. The bars must be perfectly straight before boring.

87. The holes shall be in the centre of the head and on the centre line of the bar.

88. All eye-bars shall be annealed.

Machine Work Facing.

89. All abutting surfaces in compression members shall be truly faced to even bearings, so that they shall be in such contact throughout as may be obtained by such means.

90. The ends of riveted floor girders shall be faced true and square.

Pin Holes.

91. Pin holes shall be bored truly parallel with one another and at right angles to the axis of the member unless otherwise shown in drawings; and in pieces not adjustable for length, no variation of more than 1-64 of an inch for every 20 feet will be allowed in the length between centres of pin holes.

92. Bars which are to be placed side by side in the structure shall be bored at the same temperature, and shall be of such equal length that, upon being piled on each other, the pins shall pass through the holes at both ends at the same time without driving.

Pins.

93. All pins shall be accurately turned to a gauge, and shall be straight and smooth.

Play in Pin Holes.

94. The clearance between pin and pin hole shall be 1-50 of an inch for pins up to $3\frac{1}{2}$ inches in diameter, which amount shall be gradually increased to 1-32 of an inch for pins 6 inches in diameter and over.

Pilot Nuts.

95. All pins shall be supplied with steel pilot nuts, for use during erection.

Workmanship.

96. All workmanship shall be first-class in every particular.

STEEL.

Process of Manufacture.

97. All steel must be made by the Open Hearth process, and if by acid process, shall contain not more than .08 per cent. of phosphorus, and if by basic process, not more than .05 per cent. of phosphorus, and must be uniform in character for each specified kind.

Finish.

98. The finished bars, plates and shapes, must be free from injurious seams, flaws or cracks, and have a clean, smooth finish.

Test Pieces.

99. The tensile strength, limit of elasticity and ductility, shall be determined from a standard test-

piece, cut from the finished material, of at least ½ square inch section. All broken samples must show a silky fracture of uniform color.

Annealed Test Pieces.

100. Material which is to be used without annealing or further treatment is to be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimen representing such material is to be similarly treated before testing.

Marking.

101. Every finished piece of steel shall be stamped with the blow number identifying the melt.

Physical Properties.

102. Steel shall be of three grades: *Rivet, Soft* and *Medium.*

Rivet Steel.

103. *Rivet Steel* shall have: Ultimate strength, 48,000 to 58,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 26 per cent. Bending test, 180 degrees flat on itself, without fracture on outside of bent portion.

Soft Steeel.

104. *Soft Steel* shall have: Ultimate strength, 52,000 to 62,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 25 per cent. Bending test, 180 degrees flat on itself, without fracture on outside of bent portion.

Medium Steel.

105. *Medium Steel* shall have: Ultimate strength, 60,000 to 70,000 pounds per square inch. Elastic limit, not less than one-half the ultimate strength. Elongation, 22 per cent. Bending test, 180 degrees to a diameter equal to thickness of piece tested, without fracture on outside of bent portion.

Full Size Test of Steel Eye Bars.

106. Full size test of steel eye-bars shall be required to show not less than 10 per cent. elongation in the body of the bar, and tensile strength not more than 5,000 pounds below the minimum tensile strength required in specimen tests of the grade of steel from which they are rolled. The bars will be required to break in the body but should a bar break in the head, but develop 10 per cent. elongation and the ultimate strength specified, it shall not be cause for rejection, provided not more than one third of the total number of bars tested break in the head; otherwise the entire lot will be rejected.

Pin Steel.

107. Pins made of either of the above mentioned grades of steel shall, on specimen test pieces

cut from finished material, fill the requirements of the grade of steel from which they are rolled, excepting the elongation, which shall be decreased 5 per cent, from that specified.

Drifting.

108. Punched rivet holes, pitched two diameters from a sheared edge, must stand drifting until the diameter is one third larger than the original hole, without cracking the metal.

Slabs for Plates.

109. The slabs for rolling plates shall be rolled from ingots of at least twice their cross-section.

Pins.

110. Pins up to 7 inches diameter shall be rolled.

111. Pins exceeding 7 inches diameter shall be forged under a steel hammer striking a blow of at least 5 tons. The blooms to be used for this purpose shall have at least three times the sectional area of the finished pins.

Variation in Weight.

112. A variation in cross-section or weight of rolled material of more than $2\frac{1}{2}$ per cent. from that specified, may be cause for rejection.

Steel Castings.

113. Steel casting shall be made of Open Hearth Steel containing from .25 to .40 per cent. carbon and not over .08 per cent. of phosphorus, and shall be practically free from blow holes.

Cast Iron.

114. Except where chilled iron is specified, all castings shall be of tough, gray iron, free from injurious cold shuts or blow holes, true to pattern, and of workmanlike finish. Test bars one inch square, loaded in middle between supports 12 inches apart, shall bear 2,500 pounds or over, and deflect 0.15 of an inch before rupture.

TIMBER.

Timber.

115. The timber shall be strictly first-class spruce, white pine, Douglas fir, Southern yellow pine, or white oak bridge timber; sawed true and out of wind, full size, free from wind shakes, large or loose knots, decayed or sapwood, wormholes or other defects impairing its strength or durability.

PAINTING.

Painting.

116. All iron work before leaving the shop shall be thoroughly cleaned from all loose scale and rust, and be given one good coating of pure boiled linseed oil, well worked into all joints and open spaces.

117. In riveted work, the surfaces coming in contact shall each be painted before being riveted together.

118. Pieces which are not accessible for painting after erection shall have two coats of paint.

119. The paint shall be of good quality of oxide of iron paint, mixed with pure linseed oil, or such as may be specified in contract.

120. After the structure is erected, the iron work shall be thoroughly and evenly painted with two additional coats of paint, mixed with pure linseed oil, of such quality and color as may be selected.

121. Pins, pin holes, screw threads and other finished surfaces shall be coated with white lead and tallow before being shipped from the shop.

INSPECTION.

Inspection.

122. All facilities for inspection of material and workmanship shall be furnished by the contractor to competent inspectors, and the engineer and his inspectors shall be allowed free access to any part of the works in which any portion of the material is made.

123. The contractor shall furnish, without charge, such specimens (prepared) of the several kinds of material to be used as may be required to determine their character.

TESTING.

124. Full sized parts of the structure may be tested at the option of the purchaser; but, if tested to destruction, such material shall be paid for at cost, less its scrap value, if it proves satisfactory. Testing.

125. If it does not stand the specified tests, it will be considered rejected material, and be solely at the cost of the contractor, unless he is not responsible for the design of the work.

GENERAL DATA

For bridge over ....at
........town of..............State of.........
Length and general description:................
....
....
Skew, or angle of current with centre line of bridge
....
Width of Roadway.........................
Number and width of Footwalks................
Class of Bridge.....floor (solid or planking, etc)..
Stringers ....
Number of Street Car Tracks...................
Location " " " " ....
Dimensions of Bridge Seat and Piers, if built......
....
Distance Floor to High Water.................
" " " Low " ....
Depth of Low Water..................... ....
" " Ordinary Stage ....
Distance Top of Floor to Lowest Point of Steel
Work, if fixed by local conditions............
Character of River Bottom...................
Are Piles necessary for False Work?............
Distance to be Hauled..........................
Name of nearest Railroad Station..............
Remarks ....
....

TABLE I.

UNIFORM LIVE LOAD FOR THE TRUSSES.

CLASS A.			CLASS B.		
Span in feet	Pounds per Lineal Foot of each Street Car Track	Pounds per Square Foot of remaining Floor Surface	Span in feet	Pounds per Lineal Foot of each Street Car Track	Pounds per Square Foot of remaining Floor Surface
UP TO 100	1800	100	UP TO 100	1800	80
105	1770	99	105	1770	79
110	1740	98	110	1740	78
115	1710	97	115	1710	77
120	1680	96	120	1680	76
125	1650	95	125	1650	75
130	1620	94	130	1620	74
135	1599	93	135	1590	73
140	1560	92	140	1560	72
145	1530	91	145	1530	71
150	1500	90	150	1500	70
155	1470	89	155	1470	69
160	1440	88	160	1440	[illegible]
165	1410	87	165	1410	[illegible]
170	1380	86	170	1380	66
175	1350	85	175	1350	65
180	1320	84	180	1320	64
185	1290	83	185	1290	63
190	1260	82	190	1260	62
195	1230	81	195	1230	61
200 AND OVER	1200	80	200 AND OVER	1200	60

CLASS C.

UP TO 100	1200	80	155	1090	69
105	1190	79	160	1080	68
110	1180	78	165	1070	67
115	1170	77	170	1060	66
120	1160	76	175	1050	65
125	1150	75	180	1040	64
130	1140	74	185	1030	63
135	1130	73	190	1020	62
140	1120	72	195	1010	61
145	1110	71	200 AND OVER	1000	60
150	1100	70			

TABLE I.—(CONTINUED.)

UNIFORM LIVE LOAD FOR THE TRUSSES.

CLASS D.		CLASS E		CLASS E_2	
Span in feet	Pounds per Square foot of Floor Surface	Span in feet	Pounds per Lineal Foot of each Car Track	Span in feet	Pounds per Lineal Foot of each Car Track
UP TO 75	80	UP TO 100	1800	UP TO 100	1200
80	79	105	1770	105	1190
85	78	110	1740	110	1180
90	77	115	1710	115	1170
95	76	120	1680	120	1160
100	75	125	1650	125	1150
105	74	130	1620	130	1140
110	73	135	1590	135	1130
115	72	140	1560	140	1120
120	71	145	1530	145	1110
125	70	150	1500	150	1100
130	69	155	1470	155	1090
135	68	160	1440	160	1080
140	67	165	1410	165	1070
145	66	170	1380	170	1060
150	65	175	1350	175	1050
155	64	180	1320	180	1040
160	63	185	1290	185	1030
165	62	190	1260	190	1020
170	61	195	1230	195	1010
175	60	200 AND OVER	1200	200 AND OVER	1000
180	59				
185	58				
190	57				
195	56				
200 AND OVER	55				

TABLE II.

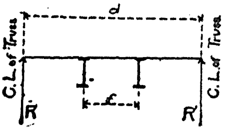
MAXIMUM MOMENTS M, END SHEARS S, AND FLOORBEAM REACTIONS R, PER STRINGER FOR A CONCENTRATED LOAD OF 24, 18, 12 AND 6 TONS ON 2 AXLES 10 FEET CENTRES.

Span L in feet	24 TONS		18 TONS		12 TONS		6 TONS		Span L in feet
	Road and Track Stringers of Class A — Track Stringers of Class B — Track Stringers of Class E1		Track Stringers of Class C — Track Stringers of Class E2		Road Stringers of Class B — Road Stringers of Class C		Road Stringers of Class D		
	S=R in lbs.	M in foot lbs.	S=R in lbs.	M in foot lbs.	S=R in lbs.	M in foot lbs.	S=R in lbs.	M in foot lbs.	
10	12000	30000	9000	22500	6000	15000	3000	7500	10
11	13000	33000	9800	24800	6500	16500	3300	8300	11
12	14000	36000	10500	27000	7000	18000	3500	9000	12
13	14800	39000	11100	29300	7400	19500	3700	9800	13
14	15400	42000	11600	31500	7700	21000	3900	10500	14
15	16000	45000	12000	33800	8000	22500	4000	11300	15
16	16500	48000	12400	36000	8300	24000	4100	12000	16
17	16900	51000	12700	38300	8500	25500	4200	12800	17
18	17300	56300	13000	42300	8700	28200	4300	14000	18
19	17700	61900	13300	46500	8800	31000	4400	15500	19
20	18000	67500	13500	50600	9000	33800	4500	16900	20
21	18300	73100	13700	54900	9100	36600	4600	18300	21
22	18500	78800	13900	59000	9300	39400	4600	19700	22
23	18800	84500	14100	63400	9400	42300	4700	21100	23
24	19000	90300	14300	67700	9500	45100	4800	22600	24
25	19200	96000	14400	72000	9600	48000	4800	24000	25
26	19400	101800	14500	76300	9700	50900	4800	25400	26
27	19600	107600	14700	80700	9800	53800	4900	26900	27
28	19700	113400	14800	85000	9900	56700	4900	28300	28
29	19900	119200	14900	89400	9900	59600	5000	29800	29
30	20000	125000	15000	93800	10000	62500	5000	31300	30
31	20100	130800	15100	98100	10100	65400	5000	32700	31
32	20300	136700	15200	102500	10100	68300	5100	34200	32
33	20400	142500	15300	106900	10200	71300	5100	35600	33
34	20500	148400	15400	111300	10200	74200	5100	37100	34
35	20600	154300	15400	115700	10300	77100	5100	38600	35
36	20700	160200	15500	120100	10300	80100	5200	40000	36
37	20800	166100	15600	124500	10400	83000	5200	41500	37
38	20800	172000	15600	129000	10400	86000	5200	43000	38
39	20900	177800	15700	133400	10500	88900	5200	44500	39
40	21000	183800	15800	137800	10500	91900	5300	45900	40

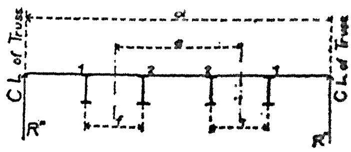
TABLE III.

MAXIMUM END REACTIONS R OF FLOORBEAMS OF CLASSES E_1 AND E_2 FOR SINGLE AND DOUBLE TRACK.

SINGLE TRACK



DOUBLE TRACK



Floorbeam Moment $=\frac{R'}{2}(d-f)$

Length L in ft.	R' IN POUNDS.		Length L in ft.	R'' IN POUNDS.	
	Class E1 24 Tons	Class E2 18 Tons		Class E1 24 Tons	Class E2 18 Tons
10	12000	9000	10	24000	18000
11	13100	9800	11	26200	19600
12	14000	10500	12	28000	21000
13	14800	11100	13	29600	22200
14	15400	11600	14	30800	23200
15	16000	12000	15	32000	24000
16	16500	12400	16	33000	24800
17	16900	12700	17	33800	25400
18	17300	13000	18	34600	26000
19	17700	13300	19	35400	26600
20	18000	13500	20	36000	27000
21	18300	13700	21	36600	27400
22	18500	13900	22	37000	27800
23	18800	14100	23	37600	28200
24	19000	14300	24	38000	28600
25	19200	14400	25	38400	28800
26	19400	14500	26	38800	29000
27	19600	14700	27	39200	29400
28	19700	14800	28	39400	29600
29	19900	14900	29	39800	29800
30	20000	15000	30	40000	30000
31	20100	15100	31	44200	30200
32	20300	15200	32	40600	30400
33	20400	15300	33	40800	30600
34	20500	15400	34	41000	30800
35	20600	15400	35	41200	30800
36	20700	15500	36	41400	31000
37	20800	15600	37	41600	31200
38	20800	15600	38	41600	31200
39	20900	15700	39	41800	31400
40	21000	15800	40	42000	31600

Floorbeam Moment at $\begin{cases} 1 \ldots = \frac{R'}{2}(d-e-f) \\ 2 \ldots = \frac{R'}{2}(d-e) \end{cases}$

TABLE IV.

STANDARD BEAM BRIDGES FOR CLASS D.

Length out to out of Beams.	12′ WIDE.	14′ WIDE.	16′ WIDE.	18′ WIDE.	20′ WIDE.	22′ WIDE.
10′ to 14′	3—7″ Is 15 lb. 2—7″ [s 9¾ lb.	4—7″ Is 15 lb. 2—7″ [s 9¾ lb.	5—7″ Is 15 lb. 2—7″ [s 9¾ lb.	5—7″ Is 15 lb. 2—7″ [s 9¾ lb.	6—7″ Is 15 lb. 2—7″ [s 9¾ lb.	6—7″ Is 15 lb. 2—7″ [s 9¼ lb.
15′ to 18′	3—8″ Is 18 lb. 2—8″ [s 11¼ lb.	4—8″ Is 18 lb. 2—8″ [s 11¼ lb.	5—8″ Is 18 lb. 2—8″ [s 11¼ lb.	5—8″ Is 18 lb. 2—8″ [s 11¼ lb.	6—8″ Is 18 lb. 2—8″ [s 11¼ lb.	6—8″ Is 18 lb. 2—8″ [s 11¼ lb.
19′ to 22′	3—9″ Is 21 lb. 2—9″ [s 13¼ lb.	4—9″ Is 21 lb. 2—9″ [s 13¼ lb.	5—9″ Is 21 lb. 2—9″ [s 13¼ lb.	5—9″ Is 21 lb. 2—9″ [s 13¼ lb.	6—9″ Is 21 lb. 2—9″ [s 13¼ lb.	6—9″ Is 21 lb. 2—9″ [s 13¼ lb.
23′ to 26′	3—10″ Is 25 lb. 2—10″ [s 15 lb.	4—10″ Is 25 lb. 2—10″ [s 15 lb.	5—10″ Is 25 lb. 2—10″ [s 15 lb.	5—10″ Is 25 lb. 2—10″ [s 15 lb.	6—10″ Is 25 lb. 2—10″ [s 15 lb.	6—10″ Is 25 lb. 2—10″ [s 15 lb.
27′ to 30′	3—12″ Is 31½ lb. 2—12″ [s 20½ lb.	4—12″ Is 31½ lb. 2—12″ [s 20½ lb.	5—12″ Is 31½ lb. 2—12″ [s 20½ lb.	5—12″ Is 31½ lb. 2—12″ [s 20½ lb.	6—12″ Is 31½ lb. 2—12″ [s 20½ lb.	6—12″ Is 31½ lb. 2—12″ [s 20½ lb.
31′ to 35′	3—15″ Is 42 lb. 2—15″ [s 33 lb.	4—15″ Is 42 lb. 2—15″ [s 33 lb.	5—15″ Is 42 lb. 2—15″ [s 33 lb.	5—15″ Is 42 lb. 2—15″ [s 33 lb.	6—15″ Is 42 lb. 2—15″ [s 33 lb.	6—15″ Is 42 lb. 2—15″ [s 33 lb.
36′ to 40′	5—18″ Is 55 lb.	6—18″ Is 55 lb.	7—18″ Is 55 lb.	7—18″ Is 55 lb.	8—18″ Is 55 lb.	8—18″ Is 55 lb.

NOTE—Clear span under Coping is 2 feet less than length out to out of beams.

TABLE V.

PERMISSIBLE COMPRESSIVE STRAINS.

p=strain allowed in lbs. per sq. in.; l=length; r=least radius of gyration; (both in inches).

Soft steel; $p = \dfrac{15,000}{1 + \dfrac{l^2}{13,500r^2}}$ Medium steel; $p = \dfrac{17,000}{1 + \dfrac{l^2}{11,000r^2}}$

$\frac{l}{r}$	Soft Steel	Med Steel	$\frac{l}{r}$	Soft Steel	Med Steel	$\frac{l}{r}$	Soft Steel	Med Steel
10	14900	16850	50	12660	13850	90	9370	9790
12	14840	16780	52	12500	13650	92	9220	9610
14	14780	16710	54	12340	13440	94	9060	9420
16	14720	16610	56	12180	13230	96	8910	9240
18	14650	16510	58	12010	13020	98	8760	9080
20	14560	16410	60	11840	12810	100	8610	8910
22	14480	16290	62	11670	12600	102	8470	8740
24	14400	16150	64	11500	12390	104	8320	8570
26	14280	16020	66	11340	12180	106	8180	8410
28	14180	15870	68	11140	11970	108	8050	8250
30	14070	15710	70	11010	11760	110	7900	8100
32	13940	15550	72	10840	11550	112	7780	7940
34	13810	15380	74	10670	11350	114	7640	7790
36	13690	15210	76	10500	11150	116	7510	7650
38	13550	15030	78	10340	10950	118	7380	7500
40	13420	14840	80	10180	10750	120	7260	7360
42	13270	14650	82	10010	10550	125	6950	7020
44	13120	14460	84	9850	10350	130	6600	6700
46	12960	14260	86	9690	10160	135	6350	6400

TABLE VI.

MAXIMUM BENDING MOMENTS ON PINS.

With extreme Fibre Strains of 22000 pounds per square inch for Soft Steel, and 25000 pounds per square inch for Medium Steel.

Diam. of Pin in Inches.	Area of Pin in Square Inches.	Moments in Inch-Pounds.		Diam. of Pin in Inches.	Area of Pin in Square Inches.	Moments in Inch-Pounds.	
		22000 lbs. per sq. in.	25000 lbs. per sq. in.			22000 lbs. per sq. in.	25000 lbs. per sq. in.
2	3.142	17280	19600	6½	33.183	593100	674000
2⅛	3.547	20730	23600	6⅝	34.472	628000	713700
2¼	3.976	24600	28000	6¾	35.785	664200	754800
2⅜	4.430	28900	32900	6⅞	37.122	701800	797500
2½	4.909	33700	38400	7	38.485	740800	841900
2⅝	5.412	39000	44400	7⅛	39.871	781200	887800
2¾	5.940	44900	51000	7¼	41.282	823000	935300
2⅞	6.492	51300	58300	7⅜	42.718	866300	984500
3	7.069	58300	66300	7½	44.179	911200	1035400
3⅛	7.670	65900	74900	7⅝	45.664	957500	1088100
3¼	8.296	74100	84300	7¾	47.173	1005300	1142500
3⅜	8.946	83000	94400	7⅞	48.707	1054800	1198700
3½	9.621	92600	105200	8	50.265	1105800	1256600
3⅝	10.321	102900	116900	8⅛	51.849	1158500	1316500
3¾	11.045	113900	129400	8¼	53.456	1212800	1378200
3⅞	11.793	125600	142800	8⅜	55.088	1268800	1441800
4	12.566	138200	157100	8½	56.745	1326400	1507300
4⅛	13.364	151600	172300	8⅝	58.426	1385800	1574800
4¼	14.186	165800	188400	8¾	60.132	1446900	1644200
4⅜	15.033	180800	205500	8⅞	61.862	1509800	1715700
4½	15.904	196800	223700	9	63.617	1574500	1789200
4⅝	16.800	213700	242800	9⅛	65.397	1641100	1864800
4¾	17.721	231500	263000	9¼	67.201	1709400	1942500
4⅞	18.665	250200	284000	9⅜	69.029	1779600	2022300
5	19.635	270000	306800	9½	70.882	1851800	2104300
5⅛	20.629	290700	330400	9⅝	72.760	1925900	2188500
5¼	21.648	312500	355200	9¾	74.662	2001900	2274900
5⅜	22.691	335400	381100	9⅞	76.590	2079900	2363500
5½	23.758	359300	408300	10	78.54	2159900	2454400
5⅝	24.850	384400	436800	10¼	82.52	2325900	2643100
5¾	25.967	410600	466600	10½	86.59	2500200	2841200
5⅞	27.109	438000	497700	10¾	90.76	2683200	3049100
6	28.274	466500	530200	11	95.03	2874800	3266800
6⅛	29.465	496300	564000	11¼	99.40	3075400	3494800
6¼	30.680	527300	599200	11½	103.87	3284800	3732800
6⅜	31.919	559600	635900	12	113.10	3732200	4241200

TABLE VII.

SHEARING AND BEARING VALUE OF RIVETS IN POUNDS.

Diam. of Rivet. Inches.		Area in Square Inches.	Single Shear at 11000 Lbs. per sq. in.	Bearing Value for Different Thicknesses of Plate in Inches at 22000 Pounds per Square Inch.												
Fraction.	Decimal.			$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
$\frac{3}{8}$	.375	.1104	1210	2060	2580	3090										
$\frac{1}{2}$	.500	.1963	2160	2750	3440	4130	4820	5500								
$\frac{5}{8}$	.625	.3068	3370	3440	4300	5160	6020	6880	7740	8600						
$\frac{3}{4}$	.750	.4418	4860	4130	5160	6190	7220	8250	9280	10320	11340	12380				
$\frac{7}{8}$	.875	.6013	6610	4810	6020	7220	8430	9630	10840	12040	13240	14440	15640	16840	18050	
1	1.000	.7854	8640	5500	6880	8250	9630	11000	12380	13750	15130	16500	17880	19250	20630	22000

A . Bearing Values to the right of upper zigzag lines are greater than Double Shear.
Values to the left of lower zigzag lines are less than Single Shear.

A. B. C.

185. General Specifications for Steel Railroad Bridges and Viaducts. The following specifications are those issued by the Pennsylvania Railroad in January, 1901. The author believes they embody the latest and best practice in the four important particulars, assumed live loads, methods of analysis, character of material, and workmanship. The engine live loads assumed correspond closely to Cooper's "E40" engine loading, followed by a train load of 5000 pounds per linear foot. The tables which immediately follow these specifications will be found of great service in designing bridges under these specifications. In this connection the following recommendations of a committee of the American Railway Engineering and Maintenance of Way Association (1902) are important.

First. That it is preferable for railroads to furnish detail plans of bridge work to bidders complete enough, at least, for a precise determination of the weight of the structure and for listing the mill orders by the successful bidder. If such drawings cannot be furnished, the alternative should preferably be full specifications, giving directions for the detail design of the structure, accompanied by a survey plan and all needed information concerning the work; the bids in this case to be by the pound and not accompanied by a design, the detail plans to be made later by the railroad or contractor, as may be understood.

Second. To invite a few parties (not always the same) to submit bids for the work.

Third. When detail plans are furnished, to ask for a lump sum bid or a pound price, as may be preferred by the purchaser; but when a specification only is furnished, to invariably ask for a pound price.

Fourth. To award contracts for as large groups of bridges as can be fully defined consistently with recommendation No. 1, and when required by circumstances to anticipate future requirements if necessary to protect the interests of the railroad.

Fifth. That the question of erecting the work by railroad forces or by contract should depend upon the custom, organization and equipment of each railroad concerned.

SECTION I.—GENERAL REQUIREMENTS.

1. Rolled steel will be used in general for all structures. Wrought iron will be used for loop-welded rods. Cast steel will be used for wedges, gearing, couplings and other important details of Materials.

drawbridge machinery. Cast iron will be used for minor details of drawbridge machinery, and for other work when expressly stipulated.

Standard Designs.

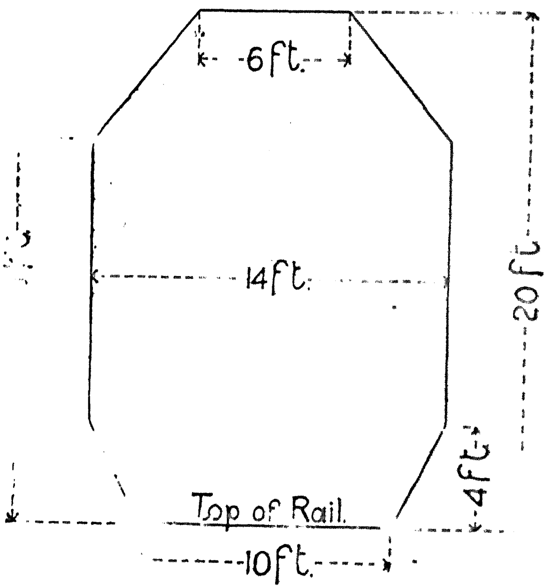
2. Rolled-beam bridges and plate-girder bridges will in general conform to the Pennsylvania Railroad Company's standard drawings. The Railroad Company will furnish diagrams showing the general dimensions of all truss bridges and of such special girder spans as are not covered by standard drawings.

Guage of Track.

3. Gauge of track is 4 feet $8\frac{1}{2}$ inches. Distance from centre to centre of double track is 12 feet 2 inches unless otherwise specified.

Clear Cross-Section. Truss Bridges.

4. A section as per accompanying diagram must be kept clear in single-track through bridges. Width to be proportionately increased for two or more tracks, and for curved line.



SECTION 2.—DATA FOR CALCULATION.

Assumed Dimensions.

5. As a basis for calculation assume the following general dimensions:—

A—Length:—

(1.) Trusses.—Distance from centre to centre of end pins.

(2.) Riveted girders.—Distance from centre to centre of bearings.
(3.) Floor beams.—Distance from centre to centre of trusses.
(4.) Track stringers.—Distance from centre to centre of floor beams.

B—Depth:—

(1.) Pin-connected trusses.—Distance from centre to centre of chord pins.
(2.) Riveted trusses.—Distance between centres of gravity of chords.
(3.) Riveted girders.—Distance between centres of gravity of flanges, or distance from back to back of flange angles if the latter dimension is the smaller of the two.

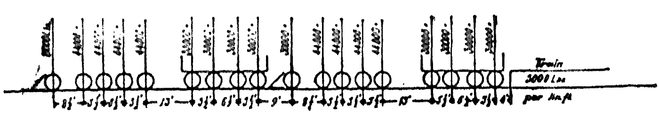
Weight of Timber. 6. In estimating the dead load the weight of timber shall be taken at $4\frac{1}{2}$ pounds per foot B. M.

Dead Load. 7. The dead load shall be assumed as uniformly distributed and made up of:—

(1.) The net suspended weight of metal in the trusses and bracing.
(2.) The weight of the metal floor system (if any.)
(3.) The weight of the wooden cross-ties or floor beams.
(4.) 160 pounds per lineal foot of track, covering the weight of rails, splices, guard rails, &c.

The above items of dead load to be properly distributed between the panel points of the loaded and the unloaded chords.

Live Load. 8. In addition to the dead load, bridges shall be designed to carry on each track a moving load consisting of two coupled "Consolidation" engines, as shown in the following diagram, followed by a uniformly distributed train load of 5000 pounds per



lineal foot of track; the moving load to be so placed as to produce the greatest stress in each member of the structure.*

Note.—For all track stringers and floor beams, and for plate-girder spans not exceeding 110 feet in length, the maximum calculated stresses due to live load are given in Table A.

Wind Loads.

9. The wind pressure shall be assumed, acting horizontally in either direction:—

(1.) At 30 pounds per square foot on the exposed surface of all trusses and the floor as seen in elevation, and on the side of a train 10 feet high, beginning at $2\frac{1}{2}$ feet above the base of rail and moving across the bridge.

(2.) At 50 pounds per square foot on all exposed surfaces of the unloaded structure.

The greater calculated stress will be used in proportioning the wind bracing.

Anchorage.

10. For determining the requisite anchorage for the loaded structure the train shall be assumed to weigh 800 pounds per lineal foot.

Longitudinal Bracing of Trestle Towers to Resist Momentum of Train.

11. For longitudinal bracing of trestle towers and similar structures, the momentum produced by suddenly stopping the train shall be considered; the coefficient of friction of wheels sliding upon rails being assumed as 0.2.

Stresses Due to Centrifugal Force.

12. When the structure is on a curve the effect due to the centrifugal force of as many trains as there are tracks shall be provided for (see Table G).

SECTION 3.—DETERMINATION OF SECTIONS.

Strain Sheet.

13. The calculation of stresses produced by the above-mentioned live and dead loads will determine the following values for each member:

M = Maximum calculated stress in member (compress or tension).

m = (1), Minimum calculated stress in members subjected to one kind of stress only (all compression or all tension); or (2), maximum calcu-

*This corresponds closely with Cooper's "E40" loading, except that we have here a train load of 5,000 lbs. per lin. ft., where Cooper has for this case 4,000 lbs.

lated stress of lesser kind, in members subjected to reversal of stress.

NOTE.—Minimum stress is understood to mean the absolute minimum; *i. e.*, in a main diagonal or post of a simple span "m" equals the calculated dead-load stress minus the maximum calculated counter stress due to live load.

$$R=\frac{m}{M}$$

Stress Increment Due to Impact, &c.

14. The maximum calculated stress (M) in each member shall be multiplied by the coefficient $(1+k)$, and the resultant quantity, $M(1+k)$, shall be regarded as the equivalent static stress in the member. (For the value of k see Tables B and C.)

Permissible Tensile Unit Stress.

15. All members shall be so proportioned that the stress, $M(1+k)$, shall not cause the tensile unit stress to exceed 15,000 pounds, nor the compressive unit stress to exceed 15,000 pounds properly reduced in accordance with Clause 16.

Permissible Compressive Unit Stress.

16. For compression members, the unit stress of 15,000 pounds per square inch shall be reduced in proportion to the ratio of the length to the least radius of gyration of the section, by the following formula:—

$$p=\frac{15{,}000}{1+\frac{l^2}{13{,}500r^2}}$$

Where
- p = permissible working stress per square inch in compression.
- l = length of piece in inches between centres of connections.
- r = least radius of gyration of section in inches. (See Table D.)

Section of Hip-Verticals and Hangers.

17. The net section of the long hip-verticals of through bridges shall be 25 per cent. in excess of the above requirements (see Clause No. 15), all details of these members being correspondingly strengthened. Short floor-beam hangers will be required to have 50 per cent. excess of strength.

Unit Stresses for Wind Bracing.

18. The same limiting unit stresses shall also be used for members strained by wind pressure or momentum of moving train, the stress increment being neglected in these cases.

Treatment of Stress Due to Centrifugal Force.

19. The stress due to centrifugal force shall be regarded as live load, and, when necessary, additions shall be made to the sections of truss chords or girder flanges until the unit stress does not exceed 17,000 pounds in tension nor 17,000 pounds, properly reduced, in compression.

In lateral bracing the stress due to centrifugal force shall be increased 50 per cent. and the unit stresses provided for in Clause 18 shall be used.

In the case of deck structures, when the curvature exceeds six degrees, the lower lateral bracing shall be designed to carry half the stress due to centrifugal force, and properly designed sway bracing shall be introduced to transfer the stress from the upper to the lower system.

Limiting Value of $\frac{l}{r}$.

20. No compression member shall have a length exceeding 100 times its least radius of gyration, excepting wind bracing, in which the length may be 120 times the least radius of gyration.

Increase of Section Required by Wind Stress, &c.

21. In case the maximum stresses in chords of bridges, or posts of trestle towers, due to wind and momentum of train, added to the maximum stresses from vertical loading and centrifugal force, properly increased, shall exceed 19,000 pounds per square inch (properly reduced for buckling in the case of compression members), additions must be made to the sections until this limit is not exceeded.

Reversal of Stress.

22. Should the stresses be reversed in any possible case, proper allowance must be made for such reversal.

Bending Moment Due to Floor Loads on Top Chords.

23. When the floor system rests directly on a continuous top chord, the latter must be so proportioned that the algebraic sum of the stresses per square inch in the outer fibres, resulting from the direct compression, and three-fourths of the maximum bending moment (the chord being considered as a beam of one panel length, supported at the ends), shall not exceed the before mentioned limiting stress in compression, the proper increment being added to each kind of loading. The bending moment at panel points shall be assumed equal but opposite in direction to that at mid panel.

General Treatment of Secondary Stresses Due to Bending.

24. All other members which are subjected to bending moment in addition to direct stress are to be similarly treated.

Stability Under Increased Live Loads.

25. To insure the stability of bridges under increased live loads, a live load shall be assumed 100 per cent. greater than that previously provided for in this specification. If the resultant stress, M $(1+k)$, produces a stress per square inch in any member more than twice the permissible unit stress previously specified, additions must be made to the sections until that limit is not exceeded. Counters, having in no case less than one and one-half square inches of section, must be provided where required by the increased live load; and in case of reversal of stress the member must be properly designed to resist such reversal.

Be Mc Pir Bo

26. Pins and bolts are to be so proportioned that the maximum stress in the extreme fibres due to bending moment shall not exceed 22,000 pounds per square inch for soft steel, nor 25,000 pounds per square inch for pin steel, the centres of bearings of the members connected by the pin or bolt being taken as points of application of bending strains.

Bearing Pressures, Pins and Rivets.

27. The bearing pressure of pins, bolts or rivets upon the projected semi-intrados (diameter x thickness) of the hole, shall not exceed 26,000 pounds per square inch for rivets, nor 22,000 pounds per square inch for pins and bolts.

Shear in Rivets, Pins and Bolts.

28. The shearing stress per square inch of section on rivets, bolts or pins shall not exceed 11,000 pounds for soft steel, nor 12,000 pounds for pin steel.

Net Sections. Tension Members.

29. Net sections must be used in all cases in proportioning tension members, and in deducting rivet holes they shall be taken $\frac{1}{8}$ of an inch larger in diameter than the nominal size of the rivets.

Field-Riveted Connections.

30. In the field-riveted connections of track stringers and floor beams, the number of rivets determined by the foregoing rules must be increased 33 1-3 per cent. in all cases. In all other field-riveted joints a 25 per cent. excess of rivets will be required if hand driven and a 10 per cent. excess if satisfactory power riveters are used.

Value of Countersunk Rivets.

31. Rivets with countersunk heads shall be assumed to have three-fourths the value of corresponding rivets with full heads.

Riveted Tension Members and Section at Pin-Holes.

32. Riveted tension members shall have a section through the pin-hole 25 per cent. in excess of the net section of the body of the member. The

section back of the pin-hole shall be at least 75 per cent. of the section through the pin-hole.

Same Gross Section in Both Flanges of Plate Girders.

33. No allowance shall in general be made for the web as resisting any of the bending moment in plate girders. The compression flange shall have the same gross sectional area as the tension flange. The unsupported length of the compression flange shall not exceed twelve times its width.

Shear in Web Rivets. Plate Girders.

34. In calculating the shearing stresses and bearing stresses in the web rivets of plate girders, the whole of the shear, with its proper increment, acting on the side of the panel next the abutment is to be considered as transferred into the flange angles in a distance equal to the depth of the girder.

Extra Rivets. Top Flanges of Plate Girders.

35. In the case of the rivets connecting the upper flange angles with the web in deck girders carrying the floor directly on the top flanges, allowance must be made for the concentrated load of a 12½ ton driver, which shall be considered as distributed over three ties.

Thickness of Web Plates.

36. The thickness of web plates shall be such that the maximum calculated shear, with its proper increment, shall not cause the shearing stress per square inch of net section of the web to exceed 13,000 pounds; but no web plate shall be less than ⅜ of an inch in thickness.

Rolled Beams and Channels as Girders.

37. Rolled beams and channels subjected to bending stresses shall be so proportioned that the stress per square inch in the outer fibers, deduced from the calculated bending moment (with its proper increment) and the moment of inertia of the section, shall not be more than 14,000 pounds. The unsupported length of the top flanges of such beams and channels shall in no case be greater than twelve times the flange width.

Minimum Sections.

38. For main members and their connections no material shall be used of less thickness than ⅜ of an inch; and for laterals and their connections no material shall be used of less thickness than 5-16 of an inch. Material of less thickness will be permitted only for lining or filling vacant spaces.

No material used in compression shall have an unsupported width of more than fifty times its thickness.

No lateral or sway rod shall be used having less than one square inch of section.

SECTION 4.—DETAILS OF CONSTRUCTION.

A.—Wooden Floor System.

39. Cross-ties shall be of white oak spaced not more than six inches apart in the clear; and, in the case of all deck and half-through girder spans, and of through truss spans having steel floor stringers, the size of ties and all details of floor construction shall be as shown on standard plans. Cross-Ties.

40. In the case of deck bridges with wooden floor beams, when the distance between centres of trusses exceeds 6 feet, the floor beams shall be proportioned for a bending moment produced by the weight of a pair of 25,000 pound drivers distributed equally over three floor beams, the extreme fibre stress in the floor beams not exceeding 1000 pounds per square inch. Wooden Floor Beams on Deck Trusses.

41. When the track is curved the outer rail is to be elevated as may be required, by cutting the cross-ties or floor beams with the proper bevel. Elevation of Rail on Curves.

42. Guard rails of long-leaved southern pine or white pine, 6 by 8 inches in size, are to be placed outside of each track rail as shown on the standard floor plans; to be notched $1\frac{1}{2}$ inches over the cross-ties, and bolted down at every fourth tie and at splices with $\frac{3}{4}$-inch bolts. The guard rails are to be spliced over ties with half-and-half joints of 6 inches lap. Wooden Guard Rails.

B.—General Details of Metal Work.

43. Adjustable members shall preferably be avoided, except in the case of counters of truss bridges. Adjustable Members.

44. All through spans shall have portals at each end, connected rigidly to end posts. They shall be as deep as the specified head room will allow, and provision shall be made in the end posts to resist the bending strain produced by the wind pressure. Portal Bracing.

45. Deck bridges shall have diagonal sway bracing at each panel, of sufficient strength to carry half the maximum stress increment due to wind and centrifugal force. Sway Bracing.

46. Pony trusses and half-through girders shall be provided with knee braces or gussets at Knee Braces.

each floor beam or strut, and at the end if practicable.

Expansion Rollers.

47. All bridges 80 feet or more in length shall have at one end nests of turned friction rollers running between planed surfaces. Rollers shall be not less than 3 inches in diameter, and the pressure per lineal inch of roller, including the proper increment, shall not exceed $1200\sqrt{d}$ ($d =$ diameter of rollers in inches).

Sliding Bearings.

48. Bridges less than 80 feet in length shall be free to move at one end on planed surfaces.

Stiff Lower Chord and Hip-Verticals.

49. Single track bridges shall have the lower chord end panels stiffened, whether the end posts are vertical or inclined; and all through spans shall have stiff hip-verticals.

Assumed Temperature Variation.

50. Provision shall be made for a free expansion and contraction of the completed structure corresponding to a variation of temperature of 150 degrees Fahrenheit.

Pressure on Masonry.

51. Bed plates shall be so proportioned that the pressure upon masonry, including the proper increment, shall not exceed 400 pounds per square inch.

Symmetrical Sections.

52. All sections shall preferably be made symmetrical and the pins placed in the line of the neutral axis.

Camber.

53. All truss bridges with parallel chords shall be cambered by making the top chord longer than the bottom chord, in the proportion of $\frac{1}{8}$ inch for each 10 feet of length.

Connections for Wind Bracing.

54. In every case the connections between the wind bracing and the chords must be of greater strength than the wind bracing itself, and so designed as to avoid as far as possible inducing bending moments in any members of the structure; and such connections must be capable of transferring the longitudinal components of the wind stresses into the main truss chords in a direct and satisfactory manner, or a separate chord must be used for the lateral system.

C.—Riveted Work.

Web Splices. Plate Girders.

55. Web plates of girders must be spliced at all joints with a plate on each side of the web, capable of transmitting the full shearing stress through the splice rivets.

56. In members subject to compression, rivets shall be so spaced that they shall not be farther apart in the direction of the stress than 16 times the thickness of the thinnest external plate connected, and not more than 50 times that thickness at right angles to the direction of stress. **Rivet Spacing. Compression Members.**

57. At the ends of compression members the pitch shall not exceed 4 diameters of the rivet, for a distance equal to twice the greatest width of the member. **Rivet Pitch at Ends of Compression Members.**

58. All joints in riveted work, whether in tension or compression members, must be fully spliced. **Splices.**

59. The distance from the edge of any piece to the centre af a rivet hole must be not less than $1\frac{1}{2}$ times the diameter of the rivet, nor exceed 8 times the thickness of the plate; and the distance between centres of rivet holes shall not be less than 3 diameters of the rivet. **Limiting Pitch of Rivets, Distance from Edge of Plate, &c.**

60. All segments of compression members connected by lacing only shall have tie plates placed as near the ends as practicable. The tie plates shall have a length not less than the greatest width of the member, and a thickness not less than one-fortieth of the distance between the lines of connecting rivets, measured at right angles to the length of the member. **Tie-Plates.**

61. Single lattice bars shall have a thickness of not less than 1-40 and double bars connected by a rivet at the intersection of not less than 1-60 of the distance between their rivets connecting them to the member; and their width shall be:— **Lattice Bars.**

For 15-inch channels, or built sections with $3\frac{1}{2}$- or 4-inch angles.	$2\frac{1}{2}$ inches ($\frac{7}{8}$-inch rivets).
For 12- and 10-inch channels, or built sections with 3-inch angles......	$2\frac{1}{4}$ inches ($\frac{3}{4}$-inch rivets.)
For 9- and 8-inch channels, or built sections with $2\frac{1}{2}$-inch angles.......	2 inches ($\frac{5}{8}$-inch rivets.)

The distance between connections of the lattice bars shall not exceed 8 times the least width of the segments connected.

62. All pin-holes shall be reinforced with additional material when necessary, so that the permissible pressure on pins shall not be exceeded. These **Pin Plates.**

reinforcing plates must contain enough rivets to transfer the proportion of pressure which comes upon them in accordance with the previously stated rules for proportioning rivets.

Wide Girder Flanges Requiring 4 Rows of Rivets. 63. Flanges of plate girders running over 14 inches in width, or projecting more than 3 inches beyond the edge of flange angles, shall have at least four lines of rivets.

Length of Cover Plates. Plate Girders. 64. In all plate girders having cover plates, at least one plate on each flange shall extend from end to end of the same, and, in general, cover plates shall be made of such lengths as to allow of at least two rows of rivets of the regular pitch being placed at each end of the plate, in addition to those theoretically required.

Webb Stiffeners. Plate Girders. 65. The webs of plate girders shall have stiffeners riveted on both sides, with a close bearing against upper and lower flange angles, at the ends and inner edges of bearing plates, and at all points of local and concentrated loads; and also when the thickness of web is less than 1-60 of the unsupported distance between flange angles, at points throughout the length of the girder, generally not farther apart than the depth of the full web plate, with a maximum limit of 5 feet.

SECTION 5.—MATERIALS.

A.—Rolled Steel.

Character of Rolled Steel. 1. In general, soft steel will be used in all parts of the work. For pins, lateral bolts and expansion rollers, however, medium steel will be used. All steel must be made by the open-hearth process, and may be either basic or acid, at the discretion of the Chief Engineer.

Phosphorus Limit. Acid. Open-Hearth Steel. 2. If made in an acid furnace, the maximum allowable amount of phosphorus in the finished product shall be six-hundredths of one per cent.

Phosphorus Limit. Basic Open-Hearth Steel. 3. If made in a basic furnace, the maximum allowable amount of phosphorus in the finished product shall be four-hundredths of one per cent.

Surface Requirements. 4. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds. All steel must be free from piping.

5. No difference of more than two and one-half per cent. from the section shown on the plans will be permitted, except in the case of extra wide plates. Permissible Excess of Weight.

6. Every finished plate, bar or angle shall be plainly stamped on one side, near the middle, with a number identifying the melt. Steel for pins shall have the melt numbers stamped on the end. Rivet steel and small pieces, not forming part of the calculated section of members, may be shipped in bundles wired together, with the melt number on a metal tag attached. Marking Finished Pieces.

B.—Cast Steel.

7. Cast steel shall be made in an open-hearth furnace, and shall fulfill the following requirements: Cast Steel. General.

(*a*) All steel castings shall be annealed. Annealing of Steel Castings.

(*b*) Every steel casting shall be made with a coupon for testing, which coupon shall be cut off after annealing, and the test shall be made from a ¾-inch round cut from the coupon. The test piece shall show an ultimate strength of at least 65,000 pounds, an elastic limit of not less than 33,000 pounds, an elongation of at least 15 per cent. in two inches, and a reduction of area of 20 per cent. at the point of fracture. Tests of Steel Castings.

(*c*) When the bearing surface of any steel casting is finished, there shall be no blow-hole visible exceeding one inch in either dimension, nor exceeding one-half a square inch in area. The length of blow-holes cut by any straight line laid in any direction shall never exceed one inch in any one foot. Soundness of Steel Castings.

C.—General Tests.

8. A sample bar not more than two inches wide, and having a sectional area of not less than one-half a square inch, shall be cut from the finished product of every melt. When taken from metal more than two inches thick, the sample may be a turned, round bar. The laboratory tests shall be made on this sample bar in its natural state, without annealing. Sample Bar.

9. When a melt is rolled into several varieties of material, each variety shall be separately tested. A variety shall consist of one of the following shapes: Sheared Plates, Universal Mill Plates, Varieties of Material to be tested.

Beams, Angles, Channels, Z Bars, Flats, Rounds, Pin Steel, Eye-bar Steel.

Measured Length of 8 Inches for Elongation Test.

10. In the laboratory tests, measurements to determine elongation shall be made on an original length of eight inches.

Bending Test.

11. A piece of each sample bar shall be bent cold 180 degrees, and closed up against itself. In the case of "pin steel" the test shall be considered satisfactory if no crack nor flaw appear on the outside of the bent portion until the diameter of the circle around which the specimen is bent has become less than the thickness of the sample bar. Samples of "soft steel" will be further required to close upon themselves without developing any crack or flaw on the outside of the bent portion before the test shall be considered satisfactory.

Drifting Test.

12. The ductility of the metal must be such that a punched hole ¾ inch in diameter, the center of which is not more than one and one-half inches from the sheared or rolled edge of the piece, may be enlarged by drifting to a diameter 50 per cent. greater than the original hole without cracking the specimen at any point.

Ultimate Strength, Elastic Limit, &c.

13. The sample bar shall be tested in a lever machine, and shall fulfill the following requirements:

	Ultimate Strength.	Elastic Limit.	Elongation.	Reduction of Area.
Pin Steel......	62,000 to 70,000 lbs.	32,000 lbs.	15 per cent.	40 per cent.
Soft Steel......	52,000 to 62,000 lbs.	28,000 lbs.	25 per cent.	50 per cent.
Rivet Steel......	48,000 to 56,000 lbs.	28,000 lbs.	28 per cent.	56 per cent.

Fracture.

14. The entire fracture shall be silky.

Minimum Limits.

15. The requirements for Elastic Limit, Elongation and Reduction of Area are minima, and no steel will be accepted which fails to meet these requirements, except as provided in Clause 16.

Duplicate Tests, When Allowed.

16. Duplicate tests may be made when the sample tested fulfills five of the six requirements. If the second test and also the average of both tests meet all the requirements the melt may be accepted.

Chemical Analyses.

17. Analyses shall be made showing the amount of phosphorus, carbon, sulphur, silicon and manganese whenever required, the drillings for these analyses being taken directly from the finished material.

D.—Full-Sized Eye-bar Tests.

18. The eye-bars required for full-sized tests and those required for the structure shall be made at one time. The test bars shall be selected by the inspector and must be fair average specimens of those which would be classed as good bars, acceptable for the work. No bar which is known to be defective in any way shall be selected for testing. Selection of Eye-Bars for Test.

19. The test bars shall show an elastic limit of not less than 27,000 pounds and an ultimate strength of not less than 48,000 pounds per square inch of section. Elastic Limit and Ultimate Strength of Test Bars.

20. The test bars will be required to develop an average stretch of 16 per cent. and a minimum stretch of 14 per cent. before breaking. The elongation to be measured on a gauged length of 10 feet, including the fracture. Elongation of Test Bars.

21. The specified elongations are minima, and a failure in these requirements will be sufficient cause for condemning the bars represented by the test. Minimum Limit of Elongation.

22. In general, bars will be required to break in the body. When a bar breaks in the head, but develops 14 per cent. elongation before breaking, a second bar shall be selected from the same lot. If this bar breaks in the body and the average elongation of the two bars is not less than 16 per cent., the bars of this lot may be accepted. Location of Fractures.

23. If more than one-third of all the bars tested break in the head, this shall be deemed sufficient cause for the rejection of the entire bill of eye-bars. Condemnation if Bars Break in Head.

SECTION 6.—WORKMANSHIP.

24. All workmanship must be of the best kind now in use. Where there is any uncertainty as to the quality of the work required by the plans or specifications, it shall be the duty of the inspector to require the best class of work which any interpretation would admit of. Quality of Workmanship in General.

25. All plates, angles and shapes shall, when necessary, be carefully straightened at the shop before assembling. Straightening Material.

26. The nominal size of rivets shown on the plans shall be understood to be the actual size of the cold rivet before heating. Size of Rivets.

Rivet Hole 1-16 Inch Larger than Cold Rivet.

27. The diameter of the finished rivet hole shall be not more than one-sixteenth of an inch greater than the diameter of the cold rivet, and shall always be of such size that the hot rivet shall not drop freely into the hole, but shall require a slight pressure to force it in.

Reaming all Holes When Material Exceeds 5-8 Inch in Thickness.

28. Soft steel up to a thickness of $\frac{5}{8}$ inch may be punched without subsequent reaming. Soft steel of greater thickness than $\frac{5}{8}$ inch must be punched with holes $\frac{1}{8}$ inch less in diameter than the size of the rivets shown on the drawings, and the holes then reamed to the proper size.

Reaming Must be Done After Assembling.

29. All reaming of rivet holes must be done after the various pieces have been punched and assembled. After reaming, every hole shall be entirely smooth, showing that the reaming tool has everywhere touched the metal.

Cleaning and Painting Contact Surfaces.

30. Before assembling, the several pieces shall be cleaned. The surfaces in contact shall then be painted with one heavy coat of red-lead paint, and the parts assembled while the paint is fresh, and then reamed and riveted up.

Abutting Surfaces to be Faced.

31. All abutting surfaces of compression members (except the flanges of plate girders) shall be carefully faced so as to have even bearings after they are riveted up complete. Abutting members fitted with splice plates must be brought into close and forcible contact, and the rivet holes reamed in position before leaving the works; the splice plates being marked so as to go in the same position in erecting.

Compression Members to be Straight.

32. Compression members must be straight and free from kinks or buckles in the finished piece.

Facing Bearing Surfaces.

33. All bearing surfaces shall be truly faced.

Web Stiffeners to Bear.

34. The web stiffeners of plate girders shall in all cases have a close bearing against the flange angles.

Flange Angles of Stringers Must be Square and Straight.

35. The flange angles of stringers must be square and straight. The outside edges of the top angles carrying the cross-ties must never be above a true plane, and not more than 1-16 inch below a true plane coincident with the roots of the angles.

Finishing Ends of Stringers and Floor Beams.

36. The ends of all stringers and floor beams shall be squared in a facer. The header angles of stringers and floor beams shall be perfectly square and so accurately fitted that when the ends of the stringers and floor beams are faced to the figured length, the amount of metal removed shall not reduce

the thickness at the roots of the header angles by more than 1-16 inch while securing a true surface for the whole width of the connection.

37. In all fields connections, except for lateral and sway bracing, the various parts to be riveted together shall be assembled in the shop, and all open holes shall be reamed out while the parts are so assembled; or an iron templet at least one inch thick shall be made and all parts reamed to fit this templet. *Field Connections to be Shop-Fitted.*

38. All rivets, whether driven by power or by hand, shall be regular in shape, with hemispherical heads (conformable in shape and size to the standard templets of the Pennsylvania Railroad Company) concentric with the axes, absolutely tight, and shall completely fill the holes. Tightening by caulking or recupping will not be allowed. *Shape of Rivet-Heads, &c.*

39. After the working is completed, eye-bars shall be annealed in a suitable annealing furnace by heating them to a uniform dark-red heat and allowing them to cool slowly. *Annealing Eye-Bars.*

40. The thickness of the heads of eye-bars shall not be more than 1-16 inch greater than the thickness of the bar; the form of the heads to be determined by the dies in use at the works where the bars are made, provided that the heads shall be of sufficient strength to break the body of the bar. *Heads of Eye-Bars.*

41. Eye-bars shall be bored truly and at exact distances; the pin-holes to be in the axis of the bar and exactly at right angles to the planes of the flat surfaces. *Boring Eyes in Eye-Bars.*

42. When all the bars of the same panel are piled together, it shall be possible to pass the pins through both pin-holes at the same time without driving. Every bar shall be tested for this requirement. *Test for Length of Eye-Bars.*

43. Pins up to 7 inches in diameter shall be rolled. *Pins to be Rolled.*

44. All pin-holes in riveted members shall be bored or drilled after all other work is completed. They shall be bored parallel with each other and at right angles to the axis of the member, and no variation of more than 1-32 inch will be allowed in the length between centres of pin-holes. *Pin-Holes in Riveted Members.*

45. All pin-holes shall be bored with a sharp tool making a clean, smooth cut. Roughness in pin-holes will be sufficient reason for rejecting a whole member. *Smoothness of Finish. Pin-Holes.*

Play in Pin-Holes.

46. All pin-holes shall be bored to fit the pins with a play not exceeding 1-32 inch.

Shop Measurement Between Pin-Holes.

47. Shop measurements shall be made between the bearing edges of tension or compression members, with a proper allowance for the diameter of the pin. An iron standard of the same temperature as the piece measured shall always be used.

Finished Size of Pins.

48. All pins shall be accurately turned to a gauge, and shall be of full size throughout.

Cleaning and Oiling all Material Before Shipment.

49. In general, all material shall be cleaned, and if necessary scraped, and given one coat of boiled linseed oil after inspection and before shipment.

Painting Inaccessible Surfaces.

50. All inaccessible surfaces shall be given one heavy coat of red lead in raw linseed oil before shipment.

Treatment of Machined Surfaces.

51. All machined surfaces shall be cleaned, oiled and given a heavy coat of white lead and tallow after inspection and before shipment.

Specifications Binding on Sub-Contractors.

52. Sub-contractors are fully bound by these specifications in every respect, and free access and information is to be given by them for thorough inspection of material and workmanship, and all required test pieces, etc., properly shaped, are to be provided, as may be requested, without charge. All shipments of material not properly inspected and passed are at the risk of the principal contractor.

Use Figured Dimensions. No Alterations Unless Authorized.

53. In all cases, figured dimensions on drawings are to be taken in preference to any measurements by scale, and no alterations are to be made unless authorized in writing by the Chief Engineer or the Engineer of Bridges.

General Clauses.

Proposal.

1. Bidders shall submit sealed proposals in conformity with the terms named in the letter of invitation. When so required the proposal shall be accompanied by a strain sheet, with full information as to calculated stresses and sizes of all material.

Indemnity from Patent Suits.

2. The contractor shall bear the cost of any suit which may arise, and shall pay all damages which may be awarded in consequence of the use by said contractor of any patented device in the construction of any bridge or other work under these specifications and for the use of the Pennsylvania Railroad Company.

Detail Drawings.

3. Immediately after the award of a contract for bridge or other structural work, a complete set of drawings in detail, including the strain sheet above mentioned, shall be furnished by the contractor; the drawings to be made on the dull side of tracing linen and the size of each drawing to be 24 inches by 36 inches. Blue prints of these drawings shall be submitted to the Chief Engineer of the railroad company for his approval before work is begun in the shop.

After approval of the drawings the contractor shall furnish the Chief Engineer with 3 sets of prints for temporary use during the progress of the work, and upon completion of the work the original tracings shall be permanently filed in the office of said Chief Engineer.

WM. H. BROWN,
Chief Engineer.

WM. A. PRATT,
Engineer of Bridges.
January 1, 1901.

TABLE A.

LIVE LOADS—SPANS FROM 5 TO 110 FEET.

Spans in feet.	Moments. 1 Rail. Foot-pounds.	Shears. 1 Rail. Pounds.	Cross-girder Reactions. 1 Rail. Pounds.	Equivalent Uniform Loads in Pounds per foot of Track.		
				Moments.	Shears.	Cross-girder Reactions.
5	31300	25000	25000	20000	20000	10000
6	37500	25000	25700	16670	16670	8570
7	43800	26700	31400	14280	15260	8970
8	50000	28900	35800	12500	14450	8950
9	56300	30600	39100	11110	13600	8800
10	62500	32500	41800	10000	13000	8360
11	68800	34100	44000	9090	12400	8000
12	78400	35800	47700	8710	11930	7950
13	93500	38100	50800	8850	11720	7820
14	110000	40100	53400	8980	11460	7630
15	126500	41800	56400	9000	11150	7520
16	143000	43300	59100	8940	10830	7390
17	159500	45300	61400	8830	10660	7220
18	176000	47700	63400	8690	10600	7040
19	192500	49800	65300	8530	10480	6870
20	209000	51700	66900	8360	10340	6690
21	227900	53400	68500	8270	10170	6520
22	249600	55000	69800	8250	10000	6350
23	271200	56400	71500	8200	9810	6220
24	292900	57800	73200	8140	9630	6100
25	314700	59000	75500	8060	9440	6040
26	336400	60500	77500	7960	9310	5960
27	358200	61900	79400	7860	9170	5880
28	379900	63200	81100	7750	9030	5790
29	401700	64400	83000	7640	8880	5720
30	424000	65500	85000	7540	8730	5670
32	473200	67600	89600	7390	8450	5600
34	522400	69400	93600	7230	8170	5510
36	571600	71900	97900	7060	7990	5440
38	620900	74100	102700	6880	7800	5410
40	670100	76200	107000	6700	7620	5350
42	719300	78700	111500	6520	7500	5310
44	768500	81000	116000	6350	7360	5270
46	819700	83000	120400	6200	7220	5230
48	876000	85600	125200	6080	7130	5220
50	938700	87900	129800	6010	7030	5190
55	1099300	93900	....	5810	6830	....
60	1277300	99300	....	5680	6620	....
65	1473000	104000	....	5580	6400	....
70	1677400	109500	....	5480	6260	....
75	1899200	115700	....	5400	6170	....
80	2137600	122300	....	5340	6120	....
85	2393000	129400	....	5300	6090	....
90	2666100	135900	....	5270	6040	....
95	2939200	142300	....	5210	5990	....
100	3214600	148100	....	5140	5920	....
105	3500600	153500	....	5080	5850	....
110	3800500	159700	....	5030	5810	....

TABLE B.

COEFFICIENTS OF STRESS INCREMENT.

Case 1.—Stresses of one kind only—all compression or all tension.

$$k=\frac{1-R}{1+R}$$

R.	k.	R.	k.	R.	k.	R.	k.	R.	k.
1.00	.000	0.79	.117	0.58	.266	0.37	.460	0.16	.724
.99	.005	.78	.124	.57	.274	.36	.479	.15	.739
.98	.010	.77	.130	.56	.282	.35	.482	.14	.754
.97	.015	.76	.136	.55	.290	.34	.493	.13	.770
.96	.020	.75	.143	.54	.299	.33	.504	.12	.786
.95	.026	.74	.149	.53	.307	.32	.515	.11	.802
.94	.031	.73	.156	.52	.316	.31	.527	.10	.818
.93	.036	.72	.163	.51	.325	.30	.538	.09	.835
.92	.042	.71	.170	.50	.333	.29	.550	.08	.852
.91	.047	.70	.176	.49	.342	.28	563	.07	.869
.90	.053	.69	.183	.48	.351	.27	.575	06	.887
.89	.058	.68	.190	.47	.361	.26	.587	.05	.905
.88	.064	.67	.198	46	.370	.25	.600	.04	.923
.87	.070	.66	.205	.45	.379	.24	.613	.03	.942
.86	.075	.65	.212	.44	.389	.23	.626	.02	.961
.85	.081	.64	.220	.43	.399	.22	.639	.01	.980
.84	.087	.63	.227	.42	.408	.21	.653	.00	1.000
.83	093	.62	.235	.41	.418	.20	.667		
.82	.099	.61	.242	.40	.429	.19	.681		
.81	.105	.60	250	.39	.439	.18	.695		
.80	.111	.59	.258	.38	.449	.17	.709		

TABLE C.

COEFFICIENTS OF STRESS INCREMENT.

Case 2.—Stresses subject to reversal.

$$k = \frac{2+R}{2-R}$$

R.	k.	R.	k.	R.	k.	R.	k.	R.	k.
0.00	1.000	0.21	1.235	0.42	1.532	0.63	1.920	0.84	2.448
.01	1.010	.22	1.247	.43	1.548	64	1.941	.85	2.478
.02	1.020	.23	1.260	.44	1.564	.65	1.963	.86	2.509
.03	1.030	.24	1.273	.45	1.581	.66	1.985	.87	2.540
.04	1.041	.25	1.286	.46	1.597	.67	2.007	.88	2.571
.05	1.051	.26	1.299	.47	1.614	.68	2.030	.89	2.603
.06	1.062	.27	1.312	.48	1.632	.69	2.053	.90	2.636
.07	1.073	.28	1.325	.49	1.649	.70	2.077	.91	2.670
.08	1.083	.29	1.339	.50	1.667	.71	2.101	.92	2.704
.09	1.094	.30	1.353	.51	1.685	.72	2.125	.93	2.738
.10	1.105	.31	1.367	.52	1.703	.73	2.150	.94	2.773
.11	1.116	.32	1.381	.53	1.721	.74	2.175	.95	2.809
.12	1.128	.33	1.395	.54	1.740	.75	2.200	.96	2.846
.13	1.139	.34	1.409	.55	1.759	.76	2.226	.97	2.884
.14	1.150	.35	1.424	.56	1.778	.77	2.252	.98	2.922
.15	1.162	.36	1.439	.57	1.797	.78	2.279	.99	2.960
.16	1.174	.37	1.454	.58	1.817	.79	2.306	1.00	3.000
.17	1.186	.38	1.469	.59	1.837	.80	2.333		
.18	1.198	.39	1.484	.60	1.857	.81	2.361		
.19	1.210	.40	1.500	.61	1.878	.82	2.390		
.20	1.222	.41	1.516	.62	1.899	.83	2.419		

TABLE D.

PERMISSIBLE COMPRESSIVE STRESSES.

l=length of piece; r=least radius of gyration (both in inches).

$$p = \frac{15{,}000}{1 + \frac{l^2}{13{,}500 r^2}}$$

$\frac{l}{r}$	p	$\frac{l}{r}$	p	$\frac{l}{r}$	p	$\frac{l}{r}$	p
10	14900	38	13550	66	11340	94	9070
12	14840	40	13410	68	11170	96	8910
14	14790	42	13270	70	11010	98	8760
16	14720	44	13120	72	10840	100	8620
18	14650	46	12970	74	10670	102	8470
20	14570	48	12820	76	10510	104	8330
22	14480	50	12660	78	10340	106	8190
24	14380	52	12500	80	10180	108	8050
26	14280	54	12340	82	10010	110	7910
28	14170	56	12170	84	9850	112	7780
30	14060	58	12010	86	9690	114	7640
32	13940	60	11840	88	9530	116	7510
34	13820	62	11670	90	9370	118	7380
36	13690	64	11510	92	9220	120	7260

TABLE E.

MAXIMUM BENDING MOMENTS IN PINS.

With extreme Fibre Stresses of 22000 pounds per square inch for Soft Steel, and 25000 pounds per square inch for Medium Steel.

Diam. of Pin in Inches.	Area of Pin in Square Inches.	Moments in Inch-Pounds. 22000 lbs. per sq. in.	Moments in Inch-Pounds. 25000 lbs. per sq. in.	Diam. of Pin in Inches.	Area of Pin in Square Inches.	Moments in Inch-Pounds. 22000 lbs. per sq. in.	Moments in Inch-Pounds. 25000 lbs. per sq. in.
2	3.142	17280	19600	6½	33.183	593100	674000
2⅛	3.547	20730	23600	6⅝	34.472	628000	713700
2¼	3.976	24600	28000	6¾	35.785	664200	754800
2⅜	4.430	28900	32900	6⅞	37.122	701800	797500
2½	4.909	33700	38400	7	38.485	740800	841900
2⅝	5.412	39000	44400	7⅛	39.871	781200	887800
2¾	5.940	44900	51000	7¼	41.282	823000	935300
2⅞	6.492	51300	58300	7⅜	42.718	866300	984500
3	7.069	58300	66300	7½	44 179	911200	1035400
3⅛	7 670	65900	74900	7⅝	45.664	957500	1088100
3¼	8.296	74100	84300	7¾	47.173	1005300	1142500
3⅜	8.946	83000	94400	7⅞	48.707	1054800	1198700
3½	9.621	92600	105200	8	50.265	1105800	1256600
3⅝	10.321	102900	116900	8⅛	51.849	1158500	1316500
3¾	11.045	113900	129400	8¼	53.456	1212800	1378200
3⅞	11.793	125600	142800	8⅜	55.088	1268800	1441800
4	12.566	138200	157100	8½	56.745	1326400	1507300
4⅛	13.364	151600	172300	8⅝	58.426	1385800	1574800
4¼	14.186	165800	188400	8¾	60.132	1446000	1644200
4⅜	15.033	180800	205500	8⅞	61.862	1509800	1715700
4½	15.904	196800	223700	9	63.617	1574500	1789200
4⅝	16.800	213700	242800	9⅛	65.397	1641100	1864800
4¾	17.721	231500	263000	9¼	67.201	1709400	1942500
4⅞	18.665	250200	284000	9⅜	69 029	1779600	2022300
5	19.635	270000	306800	9½	70.882	1851800	2104300
5⅛	20.629	290700	330400	9⅝	72.760	1925900	2188500
5¼	21.648	312500	355200	9¾	74.662	2001600	2274900
5⅜	22.691	335400	381100	9⅞	76.590	2079900	2363500
5½	23.758	359300	408300	10	78.54	2159900	2454400
5⅝	24.850	384400	436800	10¼	82.52	2325900	2643100
5¾	25.967	410600	466600	10½	86.59	2500200	2841200
5⅞	27.109	438000	497700	10¾	90.76	2683200	3049100
6	28.274	466500	530200	11	95.03	2874800	3266800
6⅛	29.465	496300	564000	11¼	99.40	3075400	3494800
6¼	30.680	527300	599200	11½	103.87	3284800	3732800
6⅜	31.919	559600	635900	12	113.10	3732200	4241200

TABLE F.

SHEARING AND BEARING VALUE OF RIVETS IN POUNDS.

Diam. of Rivet Inches.	Area of Rivet in Square Inches.	Single Shear at 11000 lbs. per Square Inch.	Bearing Value for Different Thicknesses of Plate in Inches at 26000 Pounds per Square Inch.											
			$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
$\frac{1}{2}$	0.1964	2160	4060	4870	5690	6500								
$\frac{5}{8}$	0.3068	3370	5080	6090	7110	8120	9140	10150						
$\frac{3}{4}$	0.4418	4860	6090	7310	8530	9750	10970	12190	13400	14620				
$\frac{7}{8}$	0.6013	6610	7110	8530	9950	11370	12800	14220	15640	17060	18480	19910		
1	0.7854	8640	8120	9750	11370	13000	14620	16250	17870	19500	21120	22750	24370	26000

All Bearing Values above or to right of upper Zigzag Lines are greater than Double Shear.
Values below or to left of lower Zigzag Lines are less than Single Shear.

TABLE G.

CENTRIFUGAL FORCE FOR DIFFERENT SPANS AND DEGREES OF CURVATURE—ONE TRACK.

Formula $C = 220\ D\ (1 + \frac{\text{[illegible]}}{S})$

C=Centrifugal force in pounds per lineal foot of track.
D=Degree of curvature.
S=Span in feet.
Coefficient 220 is reduced by 12 for each degree of curvature above 6 degrees.

Span in Feet.	1-Degree Curve.	2-Degree Curve.	3-Degree Curve.	4-Degree Curve.	5-Degree Curve.	6-Degree Curve.	7-Degree Curve.	8-Degree Curve.	9-Degree Curve.	10-Degree Curve.	11-Degree Curve.	12-Degree Curve.
20	360	730	1090	1450	1820	2180	2400	2590	2730	2840	2900	2930
25	330	670	1000	1340	1670	2010	2210	2380	2520	2610	2680	2700
30	320	630	950	1260	1580	1890	2000	2250	2370	2470	2520	2550
40	300	580	880	1170	1460	1750	1930	2080	2190	2230	2330	2350
60	270	540	800	1070	1340	1610	1770	1910	2020	[illegible]	2140	2160
100	250	500	750	1000	1240	1490	1650	1770	1870	1940	1990	2010
200	230	470	700	940	1170	1410	1550	1670	1760	1830	1870	1890
300	230	460	690	920	1150	....	....	....	....	....		....
500	230	450	....	....	....	....	....					

P. R. R.

186. German Specifications for the Preservation of Railroad Cross-ties. The following Specifications for the preservation of railroad cross-ties are in use on the imperial German railways. They are given with approval by Mr. O. Chanute, past President of the American Society of Civil Engineers, in a paper before that Society, Vol. XLV (1901). Two methods are here given, one for pine ties and another for beech and oak ties. They are followed by specifications for testing the impregnating materials.

I. German Specifications for Impregnating Pine Railroad Cross-ties, with a Chloride of Zinc Solution with an Addition of Coal Tar Containing Carbolic Acid.

The process of impregnating by chloride of zinc solution, with addition of coal-tar oil containing carbolic acid, is divided into three parts.

1. Steaming of the ties.
2. Production of a partial vacuum and admission of the impregnating fluid.
3. Compression (forcing in) of the impregnating fluid.

The ties are loaded on iron cars, which are pushed into the impregnating cylinder, this is closed air-tight, and they are exposed to the action of steam; steaming is continued for a longer or shorter period, according to the time of year and the condition of the ties. The admission of steam into the impregnating cylinder must be regulated in such manner, that an inside pressure of 1.5 atmospheres (22 lbs. per square inch) above air pressure is reached within 30 minutes. For dry ties it will suffice to maintain this pressure in the impregnating cylinder for 30 minutes longer, but for green ties it should be kept up for another hour. For dry ties, therefore, the steaming takes at least 1 hour, while for green ties at least 1½ hours are necessary. A gauge attached to the cylinder indicates existence of the specified pressure. The valve at the bottom of the cylinder must be opened on admitting the steam, in order that the air contained in it may be driven out, but should be closed when steam begins to blow out. This valve should be opened repeatedly, as fast as steam condenses; open it at least every half-hour to draw off the water, and for the last time just before exhausting the air. When steaming is finished, the steam remaining in the impregnating cylinder is allowed to escape.

After steam is discharged a partial vacuum is produced in the cylinder containing the ties, until the vacuum gauge shows at the least a column of mercury of 60 cm. (23.6 ins.);

this partial vacuum must be maintained for ten minutes. On expiration of this time, while continually preserving the partial vacuum, allow the impregnating fluid, which meanwhile has been prepared in a separate vessel and heated to at least 65 degrees Cent. (149 degrees Fahr.), to enter the impregnating cylinder, filling it entirely. To prepare the impregnating fluid, add while heating, 1 kgr. of coal-tar oil to every 15 kgr. (6 2-3 per cent.) of the solution of zinc chloride.

To insure as perfect a mixture of the solution of zinc chloride with the coal-tar oil as possible, an effective stirring apparatus, combined with injection of steam and air, must be applied.

Next, a pressure pump is used to exert an excess of seven atmospheres above air pressure. This pressure to be maintained for not less than 30 minutes; if necessary, continue it for a longer time, until the ties have absorbed a certain amount of impregnating fluid as specified hereafter. The impregnating fluid is then run off.

The chloride of zinc solution intended for impregnating must be as nearly as possible free from foreign substances, and there must be no free acid. An admixture of other metals, notably iron, can only be allowed in a very slight percentage and only if it cannot be avoided in the manufacture. The solution must have a strength of 3.5 degrees Beaume = 1.0244 specific gravity at a temperature of 15 degrees Cent. (59 degrees Fahr.). The solution contains 1.26 per cent. of metallic zinc.

The coal-tar oil used must not contain over 1 per cent. of oils that boil below 125 degrees Cent. (257 degrees Fahr.). It must be so little volatile that its boiling point lies mainly between 150 degrees and 400 degrees Cent. (302 degrees and 752 degrees Fahr.). In no case is it permissible to have more than 25 per cent. of its weight volatilized below 235 degrees Cent. (455 degrees Fahr.). It must contain at least 20 to 25 per cent. of acid substances (creosote or oils resembling carbolic acid) that are soluble in caustic lye of soda of 1.15 specific gravity. The coal-tar oil must be entirely liquid at +15 degrees Cent. (59 degrees Fahr.), and as much as possible free from naphthaline, so that on evaporation (fractional distillation) produced in a glass vessel in groups of 50 degrees each, it shall leave a residue of not more than 5 per cent. of napthaline. Its specific gravity should not be less than [illegible] at a temperature of +15 degrees Cent. (59 degrees Fahr.) and should not exceed 1.055. To remove such impurities from the impregnating fluid as are due to the process, suitable settling (clarifying) apparatus should be provided.

The Contractor is required to report where he obtains his

supplies of zinc-chloride solution and of coal-tar oil, intended for use, and to furnish samples of the same to the Supply Office of the Imperial Railways at Strassburg in Alsace before commencing to impregnate. He will be permitted to purchase the solution of zinc chloride and the carbolized oil of coal-tar only from such factories whose samples have been approved by the Management of the Railways. The Railway Management reserves the right to test the fluids used at any time.

It is specified that the average absorption of impregnating fluid contained in every charge of the cylinder shall be the following:

A. Absorption of 35 kgr. (77 lbs.) for each tie of the first class, length of 2.70 m. (8.85 ft.).

B. Absorption of 26 kgr. (57 lbs.) for each tie of the second class, length of 2.50 m. (8.2 ft.).

C. Absorption of 310 kgr. per cubic meter (19 lbs. per cubic foot*) for ties of other dimensions.

To determine the amount of impregnating fluid absorbed by the ties; the following method must be adopted:

Weigh all ties on a platform scale placed under roof immediately before steaming them, and again after impregnating when dripping has ceased. The difference in weights equals amount of impregnating fluid absorbed. A deduction of 15 pfennigs per 10 kgr. (16 cents per 100 lbs.) will be made for shortage shown by this weighing test. In case the shortage amounts to more than one-sixth of the absorption specified, the impregnation must be repeated. If, on the other hand, the weighing shows that the ties have absorbed more than the amount specified, a bonus of 15 pfennigs for every 10 kgr. (16 cents per 100 lbs.) will be paid for such increase, up to a maximum of 15 per cent.

II. German Specifications for Impregnating Beech and Oak Railroad Cross-ties with Hot Coal Tar Oil Containing Carbolic Acid. The work of impregnating with hot carbolized oil of coal-tar (*i. e.*, oil of coal-tar containing carbolic acid) must be divided into two parts.

1. Drying of the ties, *i. e.*, withdrawing water from them.
2. Introduction of oil of coal-tar under pressure.

The ties are run into the impregnating cylinder and this is closed air-tight. Next, a partial vacuum, equal to at least 60 cm. (23.6 ins.) column of mercury, is produced in the impregnating cylinder and maintained for 10 minutes, and thereupon, while keeping up the vacuum, the hot oil of coal-tar is

*8.5 degrees *B*. corresponds to 2.62 per cent dry zinc chloride. Hence, 19 × 2.62 per cent amounts to 0.498 lb. of dry zinc chloride per cubic foot.—O. C.

made to flow in until it rises to a level that will prevent sucking over by the air pumps. The flowing in of the coal-tar oil may be accomplished all at once or at intervals, according to the dryness of the ties. While thus filling up, and afterward, the coal-tar is heated up inside the cylinder to at least 105 degrees Cent. (221 degrees Fahr.), but not higher than 115 degrees Cent. (239 degrees Fahr.), by means of steam coils. This heating should be accomplished during a space of time of not less than 3 hours. When this temperature is reached in the impregnating cylinder, it must be kept up for another hour, either with or without the partial vacuum, as may be judged necessary, in order that the ties may absorb the specified amount of oil of coal-tar.

The impregnating cylinder is connected with a pipe condenser from the instant that filling with hot coal-tar oil commences, and all the aqueous vapors driven out of the ties are condensed in this, the water being carried to a tank. This receiver must have a water gauge from which one can read off the amount of water evaporated from the ties.

After the drying of the ties or the extraction of water from them is finished, the impregnating cylinder is filled completely and the pressure pump started, which must produce a pressure of at least 7 atmospheres. This pressure is to be maintained for at least 30 minutes in treating beech ties and 60 minutes for oak ties, unless it proves necessary to prolong the time to obtain the amount of absorption specified. The oil of coal tar is then drawn off.

The coal-tar oil used must be heavy oil, derived from the distillation of coal-tar, of greenish black color, specific gravity of 1.045 to 1.100 at 15 degrees Cent. (59 degrees Fahr.), boiling point between 150 degrees and 400 degrees Cent. (302 degrees and 752 degrees Fahr.).

While making fractional distillation no oils must pass over below 150 degrees Cent. (302 degrees Fahr.) and not more than 25 per cent of the volume at temperature up to 235 degrees Cent. (455 degrees Fahr.).

The coal-tar oil must contain by volume at least 10 per cent. of carbolic acid and, at a temperature of 15 degrees Cent. (59 degrees Fahr.), must be free from naphthalene and show no sediment.

To determine percentage of carbolic acid apply agitation to the oils heated to 400 degrees Cent. (752 degrees Fahr.) with a caustic solution of soda having specific gravity of 1.15. The difference in volume of oil before and after agitation gives percentage of carbolic acid.

The Contractor is required to state source of supply for his coal-tar oil and to furnish samples to the Supply Office of

the Imperial Railways at Strassburg before he commences work of impregnation. The coal-tar oil can only be purchased from factories whose samples have been approved by the Railway Management. The Railway Management reserves the privilege of at any time testing the coal-tar oil used.

It is specified that the average absorption of coal-tar oil for every charge of the cylinder shall be:

a. For one railroad tie, 1st class, 2.70 m. (8.85 ft.) long, of oak wood, 11 kgr. (24 lbs.); of beech wood, 36 kgr. (79 lbs.).

b. For one railroad tie, 2d class, 2.50 m. (8.20 ft.) long, of oak wood, 8 kgr. (18.6 lbs.); of beech wood, 28 kgr. (61.6 lbs.).

c. For ties of other dimensions per cubic meter (35.3 cu. ft.), of oak wood, 100 kgr. (220 lbs.); of beech wood, 325 kgr. (715 lbs.).

To determine the amount of coal-tar oil absorbed by the ties, these are weighed before the impregnation and again after it, when dripping of oil has ceased, using a platform scale placed under a roof. The difference in weight is amount of coal-tar oil absorbed. Correct the weight of the ties before impregnation by deducting from it weight of water delivered by condenser to the tank and obtained from the vapors distilled while drying in hot coal-tar oil, as weight of ties is reduced to this extent by drying process. If on examination it is proved that absorption amounts to less than five-sixths of that specified, the impregnation must be repeated.

For every shortage in coal-tar oil shown by above test, a deduction of 50 pfennigs for 10 kgr. (54.5 cents per 100 lbs.) will be made, but, on the other hand, an increase in absorption will be paid for at the same rate, a maximum of 15 per cent. increase being the limit of such payment.

III. General Conditions. The Contractor is required to give eight days' notice to the Supply Office of the time of intended commencing to impregnate ties, in order that the office may send an official to supervise same. This official must be freely admitted at all times to the plant of the Contractor, and all desired information must be readily furnished him. The Contractor must furnish all necessary appliances, apparatus and labor to make tests without charge.

In case the Contractor does not supply his own ties, the parties furnishing them will be required to deliver f. o. b. cars at the station nearest to the impregnating works, provided they are shipped by rail; ties delivered by wagon or other convey-

ance will be delivered loaded at storage yards of the factory without charge.

The hauling of ties from the station to factory will be at the expense of the Contractor for impregnation. He has also to provide for unloading, piling and handling of ties as per regulations. The Contractor will be paid for this labor the amount of 8 pfennigs (1.92 cents) for each track tie and 4 pfennigs (0.96 cent) for each switch tie of 1 m. These prices cover the exepnse of labor and tools required in receiving green ties, as well as that of reloading rejected ties; payment for a tie to be made only once.

The contractor for impregnating is held liable for all damages and loss of ties that may occur from the time they are delivered to him at the railroad station, or at his works, as long as ties remain at his works. This liability includes losses by fire occurring at the impregnation works and by theft committed while ties remain there. The Contractor must pay the value of all missing ties or of such as become unserviceable previous to their return after impregnation, but is not liable for splitting. He is, however, required to furnish without charge all necessary S-hooks and bolts for drawing together the cracks occuring during storage, and has to drive or put these in according to the directions of the supervising official.

When ties are turned over to the Contractor for impregnation, they are already supplied with S-hooks needed to draw together all existing cracks. Each beech track tie is also fitted with two iron bolts running through it, about 10 cm. (4 ins.), from each end in the direction of its breadth. It is his duty, therefore, to supply, without charge, only such S hooks and bolts as may be needed thereafter, and of the same kind, and to fasten them.

On receiving the green ties they must be piled at the factory in such a way that air will circulate freely around each one. Each pile only to have length and breadth equal to length of one tie, and must contain 100 ties. The lowest layer of ties must rest on solid supports, so that they will never touch the ground. Storage yards must be thoroughly drained and have ditches if needed. Open spaces are to be left between the piles, which spaces must measure 80 cm. (32 ins.) in one direction and have a width of 40 cm. (16 ins.). This piling of ties must be finished at the latest in 14 days from receipt of same. Date of piling to be plainly marked on each pile.

For delay in completing impregnation of ties beyond time fixed by contract, unless previous express and written permission of the Imperial General Management has been obtained, the latter will collect a penalty from Contractor for such

delay, amounting to 1 per cent of the Contract value of the unfinished impregnation per week of such delay.

The Railroad Management reserves the right to employ the Contractor for impregnation to adze surface of ties in places for bed-plates of rails, as well as to bore holes for fastenings, if such work becomes necessary. This work to be done by direction of supervising official and before impregnating.

Strassburg, February....1898.
Imperial General Management of
Railways in Alsace-Lorraine.

Acknowledged: The preceding contract of............
this day the...........1....

D...................
Contractor.

IV. German Specifications for testing Chloride of Zinc and Tar Oil, used for Preserving Timber.

For the impregnation of timber there are at present two products in use; 1st, chloride of zinc; 2d, tar-oil.

Testing of Chloride of Zinc. The chloride of zinc for impregnating purposes will be manufactured as a concentrated solution, containing about 50 per cent. of anhydrous chloride of zinc. It is best to use such a strong solution for testing, and for that purpose, samples are to be taken directly from the shipping tank or carboy.

The zinc chloride solution used must be as free from impurities as possible, particularly from iron and free acid. Therefore, it is to be determined whether or not iron and acid are present.

Test for Free Acid. Twenty grammes (by weight) of the above strong zinc chloride solution are to be mixed with distilled water; the whole to amount to 100 cu. cm. (by measure), the mixture to be well shaken.

a.—There is no free acid present if the mixture, by shaking, becomes cloudy, and, particularly if after a short period of rest, flakes settle down, which will again dissolve to a clear fluid, upon the addition of a few drops of muriatic acid (H Cl.). No further test is then required.

b.—If, after shaking, the mixture remains clear, then an excess of acid is present, the amount of which can be determined by the following manipulation:

Take several reagent bottles and put in each 10 cu. cm. of the above-described mixture, then add to each bottle a measured successively increasing quantity of a solution of one-tenth normal soda. For example: Add to the first reagent bottle 0.1 cu. cm., to the second 0.2 cu. cm., to the third 0.4 cu. cm., and so

on. Shake well and observe in which bottle a remaining white flaky precipitation will settle. The proportion of soda which lies between the mixture where a precipitation is produced, and that where no precipitation is produced, exactly represents the quantity of free acid present in the solution. For example, the mixture in the bottle to which 0.2 cu. cm. of the soda solution was added, remains clear, while in the following reagent bottle, where 0.4 cu. cm. soda solution was added, a precipitation is produced; then, 0.3 cu. cm. soda solution is exactly the quantity corresponding to the free acid present in the chloride of zinc solution.

Should there be required for this test more than 0.4 cu. cm. of the one-tenth normal soda solution, then the percentage of free acid is too high in the chloride of zinc solution, and such solution must not be used for impregnation.

Testing for Iron. Take 10 cu. cm. from the above-described mixture of zinc chloride solution and distilled water, and add a few drops of concentrated nitric acid (HNO_3) and shake well. Divide this mixture into two equal parts. To one part, without diluting, add a quantity of ammonia (NH_4OH) and shake well. If this mixture remains clear, no iron is present. Through the presence of iron in the mixture, more or less brown flakes will precipitate, corresponding to the amount of iron present. Should there precipitate in the mixture a quantity of gray-white (not brown) flakes, then not only iron, but also another impurity (nearly always magnesia) is present. In this latter case a more complete test has to be made, and, therefore, the zinc chloride solution must be sent to a chemist. But this case will happen very seldom.

The second part of the mixture of 10 cu. cm. to which nitric acid was added, should be diluted with distilled water, and 5 cu. cm. of a solution of 10 per cent. yellow prussiate of potash added, the whole to be well shaken. A very ample precipitation will be produced, which will look snow-white, or very light yellowish, if the zinc chloride solution is free from iron; but in the presence of iron it will look more or less blue, according to the amount of iron. If the precipitation shows a corn flower blue color, then the zinc chloride solution surely contains a high percentage of iron and must therefore be rejected.

To avoid, in testing, the weighing of the 20 grammes of the strong solution, the use is recommended of the easier method of measuring. First find the specific gravity, at 15 degrees Celsius, of the strong concentrated zinc chloride solution. The quotient of this specific gravity into 20 grammes shows the number of cubic centimeters which must be measured off and which represent exactly 20 grammes by weight.

For instance, the specific gravity of the strong zinc chloride solution is 1.6, then 1.6 divided into 20 grammes gives the number of cubic centimeters ($\frac{20}{1.6} = 12.5$ cu. cm.) which have to be measured off to be used for testing as described before.

Testing of Tar-Oil. At a temperature of 20 degrees Celsius the tar-oil must be limpid, and to test it, shake the tar-oil well, pour a few drops on a folded filter paper, and observe whether after absorption there remain undissolved particles on top of the paper. If the amount of these is large, the tar oil must not be used for impregnation. To find the specific gravity, the tar-oil must be heated, or cooled off, to a temperature of 15 degrees Celsius; then drop slowly an hydrometer into the same, and read the number at the surface of the oil. This number indicates the specific gravity of the tar-oil at 15 degrees Celsius; small variations in temperature are of minor importance, and can be corrected closely enough by adding or subtracting 3 to the figure in the third place of the specific gravity for every 2 degrees variation from 15 degrees Celsius.

Laboratory Distillation of the Tar-Oil. By means of a funnel, 102 cu. cm. of tar-oil at about 15 degrees Celsius are to be filled into a retort, a thermometer is to be inserted, but in such a manner that the quicksilver ball shall be in or below the neck of the retort but shall not touch the oil, or will not be covered by the same. The retort must be heated slowly, until all the water, which is contained in nearly every tar-oil, is evaporated. Stronger heat can then be applied to the retort, but it must be so regulated that in one second two drops will distill over. The distilled product will be caught in a graduated glass cylinder, and the different quantities are to be read and noted which distill over from the oil (become volatile), within the various intervals of temperature, say to 125 degrees Celsius (150 degrees) from 150 degrees to 235 degrees, and again from 150 degrees to 355 degrees Celsius, and which are specified in the "Description of the Process, and Specifications" as to the composition and proportions of the impregnating fluid.

Finding the Percentage of Carbolic Acid. (Acid Constituents of the Oil.) The entire amount of the distilled tar-oil is to be mixed in a separating funnel with 50 cu. cm. of caustic soda of 1.15 specific gravity at 15 degrees Celsius, shaken well for about five minutes, after which let it stand and settle. The caustic soda absorbs the carbolic acid and precipitates; the stop-cock of the funnel is to be opened and the precipitated caustic soda is caught in a 200 cu. cm. graduated glass cylinder. The same operation must also be repeated with 50 cu. cm. of fresh caustic soda, to make sure that all carbolic acid is extracted from the oil. The caustic soda of both manipulations is then

to be combined, about two tablespoonfuls of salt ($Na\,Cl$) added and this dissolved by means of stirring; the required quantity of concentrated muriatic acid ($H\,Cl$) added, and the combination again stirred up until well mixed. After cooling off the hot mixture, read the quantity of the separated carbolic acid in percentage of cubic centimeters, and add to this number ½ per cent. for the small amount of carbolic acid still remaining in the acid solution.

All the figures obtained are to be compared with those specified in the description of the composition and proportions of the impregnating fluids. Small differences should not be cause for rejection, as small variations in testing, resulting from barometric changes, cannot be avoided, and the result of the test is influenced by them. However, the figures obtained by the above-described tests are sufficiently close to judge of the quality of the impregnating fluids. It is not advisable that the tar-oil for testing be taken directly from the shipping-tank, but it is better to take the samples from the receptacle of the apparatus in the impregnating plant from which the mixing vessels, or the impregnating cylinder (in the impregnation with pure oil) will be supplied.

The Chief of the Operating Inspection 3.

(Signed.) Seitoast.

Berlin, June 14th, 1899.

187. Filter Gravel and Sand. The following specification for the character, size, and placing of gravel and sand in a large gravity water-filter is new and is likely to be useful as filtration plants are adopted for city water supplies. It was used in the Albany Water Filtration Plant.

Depth.

Filter Gravel. On the floor of the filters and surrounding the underdrains shall be placed gravel or broken stone having a maximum depth of one (1) foot. Instructions will be given by the Engineer as to the exact arrangement and positions of the various layers when the stone commences to be received upon the ground, but the arrangement will be approximately as follows: The lower 3 inches shall consist of broken stone or gravel which will remain upon a screen with a mesh of 1 inch, and which has but very few stones over 2 inches in diameter.

Arrangement of Layers.

Above this shall be placed 2½ inches of broken stone or gravel which has passed a screen with a mesh of 1 inch, and which remains upon a screen with a clear mesh of ⅜ of an inch, and above this shall be placed 2½ inches of broken stone or gravel, which

has passed a screen with a mesh of $\frac{3}{8}$ of an inch, and which is coarser than the ordinary sand, and entirely free from fine material. The exact depth of the various layers and the meshes of the various screens may be varied somewhat, and the Contractor will be allowed to make such reasonable changes as will allow the material to be handled economically and to the best advantage, but before making any changes he shall consult with the Engineer, and no change shall be allowed which will in any way interfere with the efficiency of the filter.

Prox Wall

Gravel shall not be placed within 6 feet of the inlet or outlet chambers, nor within 2 feet of the outside or cross-walls, these spaces being reserved for filling with sand.

Selected fc Joints.

In case the gravel used for the lower layers should contain any material so fine that pieces might enter the joints of the drain pipe, the Engineer may order coarser material to be selected from the gravel or broken stone and to be placed about the joints, the quantity of such material not to exceed 1 cubic foot per joint.

Quality

The gravel for all of the layers may be broken trap rock screened to the proper sizes, or gravel screened from sand and gravel banks of a sandy nature. Gravel screened from hard pan or clayey material *cannot* be sufficiently cleaned. The gravel shall not contain more than a very small amount of shale or limestone. The gravel shall be washed entirely free from fine material so that water passing through it or agitated in contact with it will remain substantially clean. No dirt or foreign matter of any kind shall be allowed to enter the filters after beginning to place the gravel and any gravel made dirty in any way after placing shall be at once removed and replaced to the satisfaction of the Engineer.

Payment.

(164) The price bid per cubic yard for filter gravel includes the screening, washing and placing of all of the different grades above enumerated, no deduction being made for the space occupied by the underdrains.

Quality.

Filter-Sand in Place. The filter-sand shall be clean, river, beach or bank sand, with either sharp or rounded grains. It shall be entirely free from clay, dust or organic impurities, and shall, if necessary, be washed to remove such materials from it.

The grains shall, all of them, be of hard material which will not disintegrate and shall be of the following diameters:—Not more than one per cent., by weight, less than 0.13 of a millimeter nor more than ten per cent., less than 0.27 of a millimeter; at least ten per cent., by weight, shall be less than 0.36 of a millimeter, and at least seventy per cent., by weight, less than one millimeter, and no particles shall be more than five millimeters in diameter. The diameter of sand grains will be computed as the diameters of spheres of equal volumes. The sand shall not contain more than two per cent., by weight, of lime and magnesia taken together and calculated as carbonates. In all other respects the sand shall be of a quality satisfactory to the Engineer. The Contractor shall take adequate precaution to prevent foreign or polluting material from becoming mixed with the sand, and shall protect the sand from such material until the final acceptance of the work or until the filters are put in operation.

Samples Examined by Engineer.

Samples of sand fulfilling the above requirements may be seen in the offices of the Engineer, and he will examine samples of sand submitted by intending bidders and advise them whether or not they are suitable.

Placing in Layers.

The filter-sand shall be placed in the filters in four layers, each layer to be about one foot thick, and the sand shall not be dropped from a height into final position or otherwise unduly compacted. The three first layers may be filled in to only approximate depths and the surfaces need not be smoothed. The final layer shall be brought to a true and even grade, and the surface left smooth and uniform, and such allowance shall be made for settlement as the Engineer may direct.

Payment.

The price bid per cubic yard for filter sand, includes securing, transporting and placing the sand, together with all screening, washing or other cleaning which may be necessary to make it conform to the above requirements, and the final measurement shall be made in position after settling one week with water and with the filter in operation. A. H.

188. Specifications and Contract for Architect's Services. The city of New York has found it advisable to prepare a form of Specifications and contract for the engagement

of the services of architects. Modern building construction has become so complicated and involves of necessity professional services of so many kinds that it requires a very clear and specific understanding between the owner and the architect as to the exact duties of the latter. This understanding is usually limited to a more or less informal agreement which is often not reduced to writing. As a result there are very frequently serious misunderstandings between the owner and the architect as to his duties and obligations, and the time has evidently arrived when a regular form of agreement should be entered into between these two parties. Evidently a similar form might be employed in the engagement of an engineer when his remuneration consists in a fixed percentage of the cost of the work. The following form of contract has been prepared under the direction of Professor Waite, who is himself a well-known authority on the law of engineering contracts. Omitting the provisional introductory forms and the final official certificates, the document is as follows:

Words Defined.

1. That wherever in this agreement the phrase "party of the first part" or the word "City," or the words "Commissioner(s)," "President," or "Board," or a pronoun in the place of either of them is used, the name or names shall be deemed and taken to mean and intend the party of the first part to this agreement.

2. That wherever in this agreement the word Architect(s), or a pronoun in its place, is used, the same shall be deemed and taken to mean and intend the party of the second part to this agreement.

Preliminary Drawings to be Submitted for Approval.

3. That the said Architect(s) will, at their own proper cost and expense, by or before the.... .... day of..........., 190.., furnish to the said Commissioner(s) preliminary studies, sketches and drawings, consisting of general plans of each floor and general elevations and cross sections, with general outlined specifications sufficient to show general character, construction and interior finish of the proposed building or structure, together with an estimate of the cost of the said building or structure, as in said drawings and specifications set forth and described, which said preliminary drawings and specifications shall be submitted to the said Commissioner(s) for his or their approval, and that if the

said preliminary drawings, specifications and estimates herein described are not satisfactory to said Commissioner and approved by him, then the said Architect(s) shall and will revise and correct said plans, elevations, sections and specifications so that they shall conform to the suggestions, criticisms and requirements of the said Commissioner(s), and so that the estimate and cost shall be well within the appropriation or funds available for the said building or structure.

Drawings and Specifications for Bids or Estimates.

4. That the said Architect(s) will thereafter, at their own proper cost and expense, and within ....days after the approval by the Commissioner(s) of the said preliminary drawings and specifications (or the revisions thereof), provide and furnish to the said Commissioner(s) complete plans, elevations, sections and drawings of the exterior and interior, and complete working drawings with construction details sufficiently shown, and with figured dimensions given as shall, with the specifications furnished and hereafter required, enable prospective bidders and contractors to prepare and make accurate and reliable estimates of the quantities, quality and character of the several kinds of labor and materials required to erect and complete the said building, structure, works, plan, apparatus or equipment in a first-class workmanlike manner and for the purposes and uses intended.

Details.

5. That thereafter and during the erection and construction of the above, entitled work the Architect(s) shall furnish all the detail and working plans, models, drawings and sketches necessary and proper to enable the builder or contractor to provide the materials and apparatus and to build, erect, construct and complete the whole structure contemplated and comprised in the above title in a good, prompt, efficient and satisfactory manner; such plans and drawings to include all the various parts and portions of the building, structure, works, plant, apparatus and equipment, and all features of decoration and ornamentation desirable and proper to make it an artistic architectural, or engineering production.

Pipes, Conduits, etc., to be Shown.

6. That such plans and drawings shall include complete detail and working plans, elevations and sections, which shall show not only all structural features, ornamentation and decoration, but also all air, gas, steam, hot and cold water, refrigerating,

power, heating, ventilating, sanitary and electric pipes or conduits, with all connections, valves, gates, switches, cut-outs, etc., and the location of all appliances and machines operated and supplied thereby; with arrows or indexes to show the directions of the currents therein when the plant is properly working.

Number of Sets of Drawings.

7. That six sets of blue or sun prints of such plans, elevations, sections and drawings shall be furnished to the Department or Board for its use for bidders and contractors during the period that the above-entitled work is being advertised, and until the contract(s) therefor shall have been let or awarded, and that one set shall be furnished and delivered to the said Department or Board for its uses and purposes during the erection and construction of the works, and three complete sets of such plans, elevations and drawings of the said works shall be furnished to the Contractor(s) having in charge the particular work for which they are or were designed and made; and upon the final completion of the building, structure, works and appliances, the said Architect(s) shall furnish to the said Department or Board a complete set of plans, elevations and sections revised and corrected so as to agree and conform to all material changes and alterations that shall have been made, so that such plans, elevations and sections shall show the exact dimensions, shapes and locations of the said building, structure, works, plant or apparatus as it or they shall have been actually built and completed.

Personal Services.

8. That the Architect(s) shall give their personal attention to the preparation and completion of the plans, and to the erection and completion of the said work, and that only competent and skillful architects and engineers, draughtsmen, superintendents and inspectors shall be employed upon such plans and drawings and about the said work.

Builders and Sub-Contractors not to be Employed.

9. That the said Architect(s) shall not engage, employ or require the builder or contractor, or any sub-contractor to furnish any part or portion of this work, which is the subject of this employment, to prepare, provide or furnish any of the specifications, computations, plans and detail or working drawings, for or on account of the said building, structure, works or apparatus, or any portion thereof, but shall undertake, perform and furnish such services and provide such sketches, plans, details and other work-

ing drawings, as shall be required for the erection, construction, decorations and ultimate completion and operation and use of the said building, structure, works or apparatus, at his own cost and expense; but that nothing herein contained shall relieve the contractor from providing and furnishing all shop-drawings, templets, reverse templets, patterns, forms, moulds, models, tackle, etc., necessary and proper for the prompt, successful and rapid progress and early completion of the said building, structure, works, plant, apparatus and equipment.

Complete Specifications. 10. That the said Architect(s) shall prepare, provide and furnish full and complete specifications in detail for the above entitled works, which shall describe the different parts and portions of the building, structure, works, plant, apparatus or equipment proposed and all the several kinds of materials, parts and members thereof, and the manner and method to be adopted and employed for working, developing, erecting, constructing and fully completing the various parts and portions of the works, so as to carry out the intent and purpose for a complete structure for the uses and purposes for which it is intended.

Materials, etc., to be Described. 11. That such specifications shall not describe materials and apparatus and equipment in the names of patentees, manufacturers and dealers who have a monopoly therein, but shall describe and specify materials, furnishings, equipment and process in such a manner and by such descriptions, designs, tests, requirements and specific results that they may be purchased and obtained in open, competitive market; and as shall not violate the provisions or spirit of section 1554 of The Greater New York Charter.

Property in Drawings. 12. That the said drawings, including the plans, elevations and sections, and the specifications prepared, provided and furnished by the said Architect(s) are instruments of service, such *original* plans and drawings and *original* specifications are to be and shall be taken to be and remain the property of the said Architect(s), who reserve and retain all rights to the incorporeal designs exhibited therein and thereon.

Supervision, Direction and Inspection. 13. That the said Architect(s) from the beginning of the work described shall take full charge and supervision of the building, structure, plant, works, apparatus and equipment and shall furnish necessary and proper instructions, directions and draw-

ings to the contractor, his superintendents and foremen, and shall obtain and secure a first-class, workmanlike job in every particular; that he or they will inspect, examine, test and accept or reject all materials of construction provided, furnished and delivered for and to be used in or to become a part of the said building, structure, works or apparatus, whether such materials be crude or wrought, finished or ornamented materials, and will examine, inspect and accept, approve or reject, all the workmanship, skill, artistic or otherwise, that is furnished for or wrought upon or into the said building, structure or works, and so far as they conduce to the architectural, artistic or engineering features or the stability or permanence of the works as the said materials or work may or may not conform strictly to the contract, specifications and plans and to good and workmanlike construction, that he or they shall refuse, reject and require to be removed all materials or work which do not fully comply with the specifications, contract, plans and drawings prepared therefor, and will require that they be replaced by materials and work which shall conform to and with the said contract, specifications, plans and drawings and that are proper, appropriate and necessary to a complete and first-class, workmanlike job.

Building Superintendent.

14. That the said Commissioner(s) may designate or appoint a building superintendent for the general supervision and inspection of the work and such inspectors as may to him seem necessary for the proper inspection and supervision of the work to enable the Commissioner(s) to properly certify to the satisfactory progress and completion of the work and to the payments under the contract therefor, by and on behalf of the City. That the said Architect(s) will furnish to such building superintendent and inspectors all information and assistance necessary to enable them to properly inspect and report upon any work or materials furnished for and wrought into the building, structure, works, plant, apparatus or equipment.

General Undertaking.

15. Generally, that the said Architect(s) will furnish and perform all those services required for the erection and construction of the building or structure and plants, and the heating, lighting, power, including ventilation, sanitary and electrical arrangements and appliances, and will supervise and

direct and promote the erection and completion for use and occupation of the said building, structure, works and plant of which this contract is the subject.

Employment of Specialists.

16. That the said Architect(s) will at their own cost and expense secure and engage the services of such engineering or architectural specialists as they may require or as may be necessary and proper to skillfully and properly design, plan, adapt and adjust the various heating, lighting, power, ventilating, sanitary, electrical, elevator, etc., plants, apparatus and equipment for the said building, structure or works or for the ornamentation and decoration thereof, and that the said designs, plans and specifications for such heating, lighting, power, ventilating, sanitary and electric elevator plants or equipment shall, in the discretion of the Commissioner(s), be submitted to and reported upon by some independent consulting engineer of experience and reputation, to be selected and determine by the Commissioner(s), President or Board, which said consulting engineer shall be paid for his services by the said Department or Board of the City.

Lines and Levels.

17. That the said Architect(s) shall and will design, plan and conduct their work with reference to and in strict conformity with the lines, levels and grades given and determined by the City Surveyor, who shall be selected by the said Commissioner(s) to give and determine the same.

Fees or Compensation.

18. That the City hereby retains and employs the said Architect(s) to perform the aforesaid services, and for and in consideration thereof and of the observance and performance of the conditions and stipulations herein contained, it agrees to pay to the said Architect(s) in full compensation therefor the following fees or prices:

(*a*). Five per cent. (5 per cent.) upon the total cost of the building, structure, works, plant, apparatus or equipment, including all fixtures necessary to render the building, structure, works or apparatus fit for occupation or use, but not including furniture or fixtures, nor the heating, lighting, ventilating, electrical, sanitary or elevator equipment, plant or apparatus which are not or shall not be designed and supervised by the said Architect(s).

(*b*) That no special rate for monumental or decorative work or for designs for furniture, cases or apparatus in excess of the general compensation

of five per cent. (5 per cent.) upon the cost thereof shall be charged, and that no extra charge shall be made for mural or ceiling decorations, any custom of Architect(s) to the contrary notwithstanding.

(c) That the fees of consulting architects and engineers above referred to who may be retained and employed by the Commissioner(s) to examine, revise and report upon the said designs, plans, drawings and specifications of the said Architect(s), as hereinbefore provided, shall be paid by the City and not by the said Architect(s).

Fees for Partial Services.

19. That the party of the first part shall pay to the said Architect(s) for partial service as in case of the abandonment or suspension of the work, as follows:

Preliminary Studies.

(*a*) For preliminary studies and sketches, consisting of drawings, such as ground plan and general elevation and perspective view of exterior, a fee of one per cent. (1 per cent.) of the proposed or estimated cost of the work upon the completion and delivery of such preliminary studies, sketches, etc., the amount so paid to be credited on the total commission of five per cent. (5 per cent.) of the actual cost, whether the estimated cost of the building prove greater or less than the actual cost.

Drawings, etc., for Bids.

(*b*) For a full set of preliminary drawings, including such preliminary studies or sketches, etc., and such additional elevations, plans, sections, general working drawings, specifications and details as are or may be necessary to make a close estimate of the full cost as provided in sections (3) to (11) of this agreement as shall be necessary for advertising and inviting bids or estimates from contractors for the undertaking of the erection, construction and full completion thereof, a fee of two and one-half per cent. ($2\frac{1}{2}$ per cent.) of the price or sum at which the contract is awarded, or if the award be delayed for more than sixty days, then of the estimated cost.

Details.

(*c*) For all details, working-drawings and models necessary and proper for the working, finishing and decorating of all materials, stuffs, members and parts and for their incorporation and adjustment and for the skillful construction, erection and ultimate completion of the building, structure, works, plant, apparatus, and equipment, a fee of one per cent. (1 per cent.)

Supervision and Inspection. (*d*) For all services performed in the inspection, testing, acceptance and rejection and re-acceptance of materials and work, including the general supervision and direction, and including all supervision, direction and instruction to the contractor(s) or his representatives, as may be necessary for the ultimate, final and full completion of the work, and the determination of all questions and disputes, as herein provided, the balance of one and one-half per cent. ($1\frac{1}{2}$ per cent.)

Basis of Charges. 20. That the said entire fee shall be paid upon the actual cost of the building, structure, works or apparatus, and that no additional charge shall be made for alterations and additions to or in the contract and plans or for any additional time or services whatever, which is required for such alterations or changes either in the specifications or plans or in the building, structure, works, plant, apparatus or equipment itself, except and only upon a written supplemental agreement by and between the parties hereto, in which the said additional compensation shall be fixed and determined. That no allowance shall be made for traveling expenses to or from the works, or in connection therewith, and that no additional or extra charges shall be made or allowed for any professional consultations or conferences, either with the said Department or Board or with any other Department of the City, for and in connection with the said work, or with the professional or consulting engineers and architects in regard thereto. The compensation herein agreed upon shall include all fixtures necessary to render the building, structure, works, plant or apparatus fit for occupation and use, but that no extra compensation shall be asked or allowed for furniture or other articles, unless they be designed by the Architect(s) and erected or placed under his inspection and direction at the express request of the said Commissioner(s) or by resolution of the said Board.

Conferences, Hearings, etc. 21. That the above fees shall cover all professional advice and services required by the said architect(s) in the design, erection, construction and completion of the said building, structure, works, plant or apparatus, and also all conferences, hearings and meetings necessary and proper to determine any questions or disputes between the contractor or subcontractors and the said party of the first part, and

which questions and disputes it may be provided shall be heard and determined by the Architect(s) in the contracts between the said party of the first part and the said contractor(s).

Time and Manner Payment.

22. That payments to the said Architect(s) shall be made as his work progresses, and at succeeding stages of the work as follows: Upon the completion and delivery of the said plans, elevations, sections, general working drawings with constructive details sufficiently shown, and the dimensions figured to enable bidders or contractors to prepare accurate and reliable estimate of the cost thereof, and the completion and delivery of full and complete specifications for all branches and classes of work necessary to the full and ultimate completion, use and occupation of the said building and structure, as provided in Clause 19 (*b*), two and one-half per cent. (2½ per cent.); upon the completion of all details, working drawings, plans, sections and models, as provided in Clause 19 (c), one per cent. (1 per cent.), and upon the completion of said building, structure, works, plant, apparatus and equipment and their final acceptance by the City, one and one-half per cent.), or the balance that may be due and owing of the full fee or percentage of the actual cost.

Abandonment or Delay.

23. That if, at any time, the said Architect(s) shall abandon or unreasonably delay the preparation and completion of the plans, elevations, sections, details and working drawings, and the complete specifications, within the time herein specified, or as may be required by the said Commissioner(s) and as may be necessary or proper to enable the contractor(s) to prosecute the said building, structure, works, plant, apparatus or equipment with dispatch and reasonable safety so as to insure its completion within the time designated in the contract therefor, the said Commissioner(s), President or Board shall have the power to notify the said Architect(s) to discontinue all services and work provided for under this contract, by written notice to be served upon the said Architect(s) either personally or by leaving the same at their residence, and thereupon the said Architect(s) shall discontinue the said services or such part thereof as the said Commissioner(s) may designate, and the said Commissioner(s) shall have the power to employ other architects, by contract or otherwise, as he may deem advisable to perform and

Power to Employ Others.

complete the said services and work herein described, or such part thereof as he may deem necessary, and the remuneration, pay or fees of the said Architect(s) shall be determined by the scale of prices or fees herein given, it being expressly agreed and understood that the said Architect(s) shall be paid only such fees as they shall have fully earned, and as shall be due and owing under the express terms of this agreement. That whenever the City or its appropriate officer(s) shall act under this clause, or in the event of the death of the Architect(s), all drawings, plans, elevations, sketches, sections and models and all specifications, estimates, measurements and data pertaining to the building, structure, works, plant, etc., or prepared for them under the terms of or in fulfillment of this contract, shall be delivered within twenty days to the said Commissioner(s), President or Board, or to his or its authorized agent, and if the said Architect(s) shall fail or refuse, upon demand being made, to so deliver said instruments, estimates and data, then the said Architect(s) shall forfeit all rights to any further compensation under this contract for or on account of any services rendered or to be rendered.

Delivery of Plans, etc., in Case of Abandonment, Delay or Death.

Suspension.

24. That if, for any reason, it becomes necessary to postpone, suspend, delay or abandon the building, structure, works or apparatus for which these services are engaged and employed, then the said Architect(s) shall be paid only such fees as they shall have fully earned, and as shall be due and owing by the express terms of this agreement, and such postponement, suspension, delay or abandonment shall not give any cause of action for damages or for extra remuneration to the said Architect(s).

Officers of City Not Bound Personally.

25. That the payments herein provided for are to be made out of the moneys provided by the party of the first part, for the construction, erection and completion of the above entitled building, structure, work, plant or apparatus, and that these presents do not bind the said Commissioner(s) individually to make any payment or payments hereunder or on account hereof. That his or their action in the premises is binding upon the said City and its successors, and the fund hereby created for such purpose, in conformity with the statutes and The Greater New York Charter, and the acts in addition and supplemental thereto, or any amendments thereof, and un-

der which said Commissioner(s) was or were appointed, and under and by virtue of which he or they acted in these premises.

26. That the Architect(s) will be responsible for all claims made against the said City for any infringements of copyright or patent-right for or on account of the adoption and use of any designs, plans, drawings or models furnished by the said Architect(s) and used in the construction or decoration of the said building, structure or works, plant or apparatus. Copyright.

27. That this contract shall not be binding or of any force unless the Comptroller of The City of New York shall indorse hereon his certificate that there remains unexpended and unapplied, as provided in The Greater New York Charter, a balance of the appropriation or fund applicable thereto sufficient to pay the estimated expense of executing this contract, as certified by the officers making the same. Charter, Section 149.

28. That the cost of the said building, works and apparatus designed, planned and illustrated, including the Architect's fees and the cost of necessary surveys and inspection, shall be kept well within the sum of .... ($........). Cost to be Limited.

29. That it is understood and intended by the parties hereto, that the party of the second part shall provide and furnish the personal services of .... Personal Services.

....

and that this contract may not be assigned, sublet or transferred, without the express consent in writing of the said Commissioner(s), President or Board.

In witness whereof, the said The City of New York has, by the said Commissioner(s), executed this contract on behalf of the said party of the first part and the said party of the second part has executed this contract the day and year first above written, and the said parties hereto have executed this agreement in triplicate, one part of which is to remain with the said Commissioner(s), one other is to be filed with the Comptroller of The City of New Execution.

York, and the third is to be delivered to the said party hereto of the second part the day and date herein first written above.

Signatures.

....................[L. S.]
Commissioner(s).

....................[L. S.]
President.

....................[L. S.]
Secretary.

....................[L. S.]
Architect(s).

(Seal.)

J. C. W.

CONTRACTOR'S BONDS.

189. **Contract Bond or Surety.** It is a very general custom in all important work to require the contractor to furnish a bond for the faithful and complete performance of his contract. Sometimes these bondsmen or sureties sign with the contractor, as in the case of the St. Louis contracts, exemplified in article 168. It is more usual, however, to make this bond a separate document, following immediately the signatures of the contract itself.

Bonds are always executed under seal, and are therefore special contracts, since the bondsmen are not usually paid a consideration for the service rendered, and a sealed contract does not require a consideration to enforce it.

In case the original contract and specifications are deviated from in the execution of the work to any material extent, without the consent of the bondsmen, these latter are thereby released from their bond. Since such changes are nearly always made in the execution of engineering work after the contracts are signed, and since these are usually made without consulting the bondsmen, these latter are as a rule thereby released from all obligations, and the bond becomes of no effect. Even though the bondsmen be consulted in the matter of changes, they are not obliged to give their consent, and usually perhaps would not, in which case material changes could be made only by releasing the bondsmen.

To provide for such changes, without releasing the bondsman, the following clause may be added:

And the said suret . . . hereby stipulate . . . and agree . . that no change, extension, alteration or addition to the terms of the contract or specifications shall in any wise affect . . . . obligation on this bond.

The form of bond given below is that used by the city of Boston, and may be taken as a general type of such a document.

CONTRACT BOND OR SURETY.

Know all Men by these Presents,

That we ....

....

....

....

....

are held and firmly bound unto the City of Boston, in the sum of ....

....

dollars to be paid to the City of Boston, or its certain attorney, its successors and assigns, for which payment, well and truly to be made, we bind ourselves, our heirs, executors, and administrators, jointly and severally, firmly by these presents.

The Condition of this obligation is such that if the above-bounden ....

....

....

shall well and truly keep and perform all the terms and conditions of the foregoing contract for excavation for stripping and shallow flowage and for building two roads, at Basin No. 5, in Southborough, on .... part to be kept and performed, and shall indemnify and save harmless the said City of Boston, as therein stipulated, then this obligation shall be of no effect; otherwise it shall remain in full force and virtue.

In Witness Whereof, we hereto set our hands and seals on this .... day of .... in the year eighteen hundred and ninety four.

.... [SEAL.]

.... [SEAL.]

.... [SEAL.]

.... [SEAL.]

.... [SEAL.]

Signed and Sealed in presence of

....

....

....

190. Indemnity Bond. The following is a common form of bond to cover all liens which may arise from a failure of the contractor to pay for his labor and materials.

Know all Men by these Presents: That ——— of ——— as principal, and ——— of ——— as surety, are held and firmly bound unto the ——— in the penal sum of ——— dollars, to the payment of which well and truly to be made we bind ourselves, our heirs, executors, administrators and assigns firmly by these presents.

Signed this —— day of ——— 189—.

The Condition of the above Obligation is such that:

WHEREAS, the said ——— has this day entered into a contract in writing with the said ——— for the grading and construction of a certain ——— with ditches, roadways, and other works connected therewith, as more specifically set forth in said contract:

NOW, THEREFORE: If the said ——— shall well and truly perform his part of said contract, and each and every covenant and agreement therein contained, and shall indemnify and save harmless the said ——— from and against all damages which it may sustain by reason of liens for labor and materials furnished for said work, or by reason of the failure of said ——— to pay the wages and earnings of any of the——— laborers or mechanics employed by him as such contractor, in and about said work; or by reason of his failure to pay for any materials, provisions or goods of any kind furnished, or by reason of any just debts incurred in carrying on said work; and if the said ——— shall pay to the said ——— all sums of money, damages, or costs and expenses which it may be compelled to pay, or which it may sustain by reason of his failure as aforesaid, and if the said ——— shall pay all laborers, mechanics and material men, and persons who may have supplied provisions or goods of any kind, all just debts due to such persons, or to any person to whom any part of such work was given, then this obligation shall be void, otherwise of full force and effect.

——————————— [SEAL.]
——————————— [SEAL.]

APPENDIX A.

PRELIMINARY SURVEYS AND EXAMINATIONS FOR BRIDGE RENEWALS.

The following Instructions to Assistant Engineers are used by the engineer of bridges and buildings on the C., M. & St. P. R'y, and are inserted here as an illustration of the scope and character of the inquiries and investigations necessary for an intelligent solution of the problem in hand. It is only by means of such complete and detailed information that all future contingencies can be foreseen and provided for, so that there shall be no "unexpected" to happen. It is a common saying that "the unexpected always happens." In good engineering, "It is only the unexpected which can happen," since what was anticipated has been fully provided against. In the *best* engineering designs, however, every possible contingency has been foreseen and provided for, so there is no unexpected left which can happen, and hence security and permanence are assured in advance. The following instructions are a good illustration of this kind of preliminary survey of the problem which puts the engineer in a position to perfectly fit the design to all the conditions of the problem:

Instructions to Assistant Engineers in Regard to Surveys for the Renewal of Wooden Bridges with Permanent Structures.

(1) Gather information from the chief engineer's office and from the office of the engineer and superintendent of bridges and buildings relative to the grade, alignment, right-of-way for embankment and borrow pits, second track construction, contracts relating to crossings or cattle passes, recommendations already made by others as to style of reconstruction and any other matters that are liable to have a bearing on work in question.

(2) Determine the elevation of base of rail above an assumed datum across the bridge and for a distance of 1,000 feet on each side of it, at intervals of 100 feet, or less when the irregularities of the track make it necessary.

(3) Consider the question of changing grade and note the kind, condition and depth of ballast as well as other points

that will assist in determining the expense and practicability of making a change.

(4) Obtain particularly notes of the ground surface that will be covered by the proposed structure or embankment, by determining its elevation on the center line of bridge and when necessary on each side of same. These heights may be measured from the base of rail at each bent or panel point but should refer to the datum used in the survey, and additional notes should be made of intermediate irregularities that would concern the height of pedestals located between bents.

(5) Establish and note two bench marks on solid objects, conveniently located, one each way from the bridge, and which are unlikely to be disturbed during the construction of the permanent structure. For ordinary cases a track spike driven in a telegraph pole will be suitable.

(6) Note the alignment of the track at the structure and consider whether there is any evident reason for changing same.

(7) Consider the question of second track construction as concerning any change in alignment or in location of bridge. Conclude on which side of the present track the second track should be constructed and make note of the grounds for your conclusion.

(8) When track across the bridge or near the bridge is curved make full notes of elevation of outer rail. If the point of curve is so located that the elevation of outer rail on bridge is varying, determine by eye the location of point of curve and of the point where the elevation is commenced. On iron bridges the elevation should be constant when practicable.

(9) Take notes for a sketch of the water course for a sufficient distance on each side of the bridge, to determine whether a change in location of channel or an improvement in the channel is advisable, and indicate your recommendations in this regard, remembering that the most favorable condition for a bridge is usually a deep channel at right angles to the railway for some distance above and below the bridge. Contours in the immediate vicinity of the bridge should be sketched in. Ordinarily this can be done with sufficient accuracy by the eye, or by taking a few offsets.

(10) Ascertain the nature of foundations, whether soft, requiring pile foundations, or of sand, or of hard clay, or of rock. Reports should state the character, depth and dip of the strata.

(11) Ascertain present, ordinary and extreme high water marks. Inquire into cause of high water; whether by ordinary heavy rains, by water-spout, by damming from accumulations of drift or ice, or by overflow from other water courses, or from other causes which may be apparent.

(12) Note the probability of ice, drift-wood, hay, corn-stalks, fencing, etc., lodging against the proposed iron bridge.

(13) Take notes of the size of channel, area of waterway required, direction of current, etc.

(14) Ascertain if there is to be provided under the bridge a public or private roadway, wagon-pass or cattle-pass, with dimensions and conditions controlling the same.

(15) If any portion of the bridge is to be filled, make an examination of the ground and state where the material can be obtained, and whether inside of the boundaries of the right-of way, or on land which will have to be purchased.

(16) Ascertain whether any additional right-of-way is required for any purpose connected with the work, and if so note location and amount.

(17) Examine as to a suitable location for a stone yard, and for the storing of piles, timber and iron-work; also as to convenient locations for derricks and what provision will be required for suitable anchorage for derrick guys.

(18) If the proposed reconstruction involves any question of purchasing land or privileges, report the situation with advice, but avoid conversation with property owners which would in any way interfere with relations that may be established later between them and an agent authorized to make purchases or settle claims.

(19) Inquire as to the accommodations for boarding and lodging for workmen and how they can get to and from their work.

(20) Inquire into the condition of train service at the location with regard to the frequency of trains and the speed at which they ordinarily run over the bridge.

(21) If piles are to be driven, make your recommendation as to whether they should be driven with a land or track driver, and if with a track driver, state the nearest side-track to which it must retreat for passage of trains.

(22) Make preliminary estimates of the cost of the permanent structure, taking your prices from the tables of cost of iron bridges and abutments which are furnished you and from them make your recommendation for the permanent bridge.

(23) Make your recommendations as to the angles of piers and abutments, remembering that a square span is one in which its ends are at right angles to its longitudinal axis, and in a skew span the angle of skew is the enclosed angle between the end of the span and a line at right angles to its longitudinal axis.

(24) Make your recommendation as to what riprapping is required, with the amount and method of using it.

(25) Advise what is the best season of the year in which to do the work with reference to high water, ice, cold weather, interruption of traffic, facility for obtaining labor and material, etc.

(26) Report any information you can obtain with reference to using local material in the work, such as piles, timber, lumber, stone, sand, brick, etc.

(27) Avoid confusing terms in your notes. For instance the term "base of rail" is preferable to "grade." See B. & B., Rule 7 g.

FINALLY. After obtaining information on the points hereinbefore mentioned and all other data which you can find within your reach, consider the question of renewal just as if you had to make the full decision and were responsible for building the best bridge with the greatest economy and least risk; and make your report in such shape that the draughting office will have all the instruction which it requires for making the plans. This information may be furnished in writing and on a profile and map, and you are cautioned that your work will be judged by your giving the fullest accurate information with the fewest notes and the least amount of drawing.

O. B.

APPENDIX B.

General Specifications for the Testing of Hydraulic Cements, adopted by a Board of U. S. Engineer Officers in 1901, and used by the Engineer Department of the U. S. Army.*

TESTS TO BE MADE.

For selecting Portland and Puzzolan cement from among the brands offered, the Board recommends that the following tests be made:

1. For fineness of grinding.
2. For specific gravity.
3. For soundness, or constancy of volume in :
4. For time of setting.
5. For tensile strength.

For Natural cement we recommend the omission of the specific gravity and soundness tests.

On the works the Board recommends simple tests when the more elaborate tests can not well be made.

In determining the minimum requirements for cements given in the subjoined specifications we recognize that many cements that attain only fair strength neat and with sand in a short time and show marked gains of strength on further time will fulfill the requirements of the service, and that unusually high tensile strength attained in a few days after gauging is often coupled with a small or negative increase in strength in further short intervals. Unusually high tests in a short time after gauging should be regarded with suspicion, although some well-known brands of American cements show great strength in short-time tests and, so far as observed, are reliable in air and fresh water. Cement offered under such known brands should show their characteristic strength and other qualities or be suspected as spurious or adulterated, if not rejected, even though the minimum requirements of the specifications are met. The practice of offering a bonus or free gift of money in addition to the contract price for cement testing above a fixed high point should be prohibited as unnecessary, for cements so obtained are likely to be unsound in a manner not easily detected in the time usually available in testing.

It is believed that most of the very high testing Portland cements have lime in excess, the effect of which is temporarily

*The members of this Board were Major Wm. L. Marshall, Major Smith S. Leach, and Captain Spencer Crosby

masked by the use of sulphate of lime. Overlimed cements so treated are unfit for use in sea water. For such uses a chemical analysis should be required, and the quantity of sulphuric acid, as well as magnesia, be limited to a low percentage. It is not yet known that sulphate of lime in quantity less than 2 per cent is injurious to cements to be used in fresh water or in air. It masks expansives that might ultimately cause the destruction of the work, but it is not known whether this effect is permanent. Its addition is now deemed necessary to control time of setting. It makes a quick-setting cement slow setting, at the same time increasing tensile strength acquired in short time.

MANIPULATION OF CEMENTS FOR TESTS.

I. Fineness.

Place 100 parts (denominations determined by subdivisions of the weighing machine used) by weight on a sieve with 100 holes to the linear inch, woven from brass wire No. 40, Stubb's wire gauge; sift by hand or mechanical shaker until cement ceases to pass through.

The weight of the material passing the sieve plus the weight of the dust lost in air, expressed in hundredths of the original weight, will express the percentage of fineness. In order to determine this percentage the residue on the sieve should be weighed.

It is only the impalpable dust that possesses cementitious value. Fineness of grinding is therefore an essential quality in cements to be mixed with sand. The residue on a sieve of 100 meshes to the inch is of no cementitious value, and even the grit retained on a sieve of 40,000 openings to the square inch is of small value. The degree of fineness prescribed in these specifications (92 per cent) for Portland through a sieve of 10,000 meshes to the square inch is quite commonly attained in high-grade American cements, but rarely in imported brands. On the Pacific coast, where foreign cements only are in the market, this requirement may be lowered for the present to 87 per cent on No. 100 sieve.

II. Specific Gravity.

The standard temperature for specific gravity determinations is 62 degrees F., but for cement testing temperatures may vary between 60 and 80 degrees F. without affecting results more than the probable error in the observation.

Use any approved form of volumenometer or specific gravity bottle, graduated to cubic centimeters with decimal sub-

divisions. Fill instrument to zero of the scale with benzine, turpentine, or some other liquid having no action upon cements.

Take 100 grams of sifted cement that has been previously dried by exposure on a metal plate for twenty minutes to a dry heat of 212 degrees F., and allow it to pass slowly into the fluid of the volumenometer, taking care that the powder does not stick to the sides of the graduated tube above the fluid and that the funnel through which it is introduced does not touch the fluid.

Read carefully the volume of the displaced fluid to the nearest fraction of a cubic centimeter. Then the approximate specific gravity will be represented by 100 divided by the displacement in cubic centimeters.

The operation requires care.

III. Setting Qualities and Soundness.

The quantity of water and the temperature of water and air affect the time of setting. The specifications contemplate a temperature varying not more than 10 degrees from 62 degrees F., and quantities of water given herein:

For Portland cements use 20 per cent of water.

For Puzzolan cements use 18 per cent of water.

For Natural cements use 30 per cent of water.

Mix thoroughly for five minutes, vigorously rubbing the mixture under pressure; time to be estimated from moment of adding water and to be considered of importance.

Make on glass plates two cakes from the mixture about three inches in diameter, half an inch thick at middle, and drawn to thin edges, and cover them with a damp cloth or place them in a tight box not exposed to currents of dry air. At the end of the time specified for initial set apply the needle one-twelfth of an inch diameter weighted to one-fourth of a pound to one of the cakes. If an indentation is made the cement passes the requirement for initial setting, if no indentation is made by the needle it is too quick setting. At the end of the time specified for "final set" apply the needle one twenty-fourth of an inch diameter loaded to one pound. The cement cake should not be indented.

Expose the two cakes to air under damp cloth for twenty-four hours. Place one of the cakes, still attached to its plate, in water for twenty-eight days; the other cake immerse in water at about 70 degrees temperature supported in a rack above the bottom of the receptacle; raise the water gradually to the boiling point and maintain this temperature for six hours and then let the water with cake immersed cool. Examine the cakes at the proper time for evidences of expansion and distor-

tion. Should the boiled cake become detached from the plate by twisting and warping or show expansion cracks the cement may be rejected, or it may await the result of twenty-eight days in water. If the fresh-water cake shows no evidences of swelling, the cement may be used in ordinary work in air or fresh water for lean mixtures. If distortion or expansion cracks are shown on the fresh-water cake, the cement should be rejected.

Of two or more cements offered, all of which will stand the fresh-water cake test for soundness, the cements that will stand the boiling tests also are to be preferred.

IV. Tensile Strength.

Neat Tests.—Use unsifted cements. Place the amount to be mixed on a smooth, nonabsorbent slab; make a crater in the middle sufficient to hold the water; add nearly all the water at once, the remainder as needed; mix thoroughly by turning with the trowel, and vigorously rub or work the cement for five minutes.

Place the mold on a glass or slate slab. Fill the mold with consecutive layers of cement, each when rammed to be one-fourth of an inch thick. Tap each layer 30 taps with a soft brass or copper rammer weighing 1 pound and having a face three-fourths of an inch diameter or seven-tenths of an inch square with rounded corners. The tapping or ramming is to be done as follows: while holding the forearm and wrist at a constant level, raise the rammer with the thumb and forefinger about half an inch and then let it fall freely, repeating the operation until the layer is uniformly compacted by thirty taps.

This method is intended to compact the material in a manner similar to actual practice in construction, when a metal rammer is used weighing 30 pounds, with a circular head 5 inches in diameter falling about 8 inches upon layers of mortar or concrete 3 inches thick. The method permits comparable results to be obtained by different observers.

After filling the mold and ramming the last layer, strike smooth with the trowel, tap the mold lightly in a direction parallel to the base plate to prevent adhesion to the plate, and cover for twenty-four hours with a damp cloth. Then remove the briquette from the mold and immerse it in fresh water, which should be renewed twice a week for the specified time if running water is not available for a slow current. If molds are not available for twenty-four hours, remove from the molds after final set, replacing the damp cloth over the briquettes. In removing briquettes before hard-set great care should be exercised. Hold the mold in the left hand, and, after loosening the latch, tap gently the sides of the mold until they fall apart. Place the briquettes face down in the water trough.

For neat tests of Portland cement use 20 per cent of water by weight.

For neat tests of Puzzolan cement use 18 per cent of water by weight.

For neat tests of Natural cement use 30 per cent of water by weight.

Nearly all this water is retained by Portland cement, whereas only about one-third of the gauging water is retained by Puzzolan or Natural cements; from this it follows that an apparent condition of plasticity or fluidity that ultimately little injures Portland paste, very seriously injures Puzzolan or Natural mortars and concretes by leaving a porous texture on the evaporation of the surplus water.

Sand Tests.—The proportions 1 cement to 3 sand are to be used in tests of Puzzolan and Portland, and 1 cement to 1 sand in tests of Natural or Rosendale cements. Crushed quartz sand, sifted to pass a standard sieve with 20 meshes per linear inch and to be retained on a standard sieve with 30 meshes to the inch, is to be used.

After weighing carefully, mix dry the cement and sand until the mixture is uniform, add the water as in neat mixtures, and mix for five minutes by triturating or rubbing together the constituents of the mortar. This may be done under pressure with a trowel or by rubbing between the fingers, using rubber gloves. The rubbing together seems necessary to coat thoroughly the facets of the sand with the cement paste.

It is found that prolonged rubbing, when not carried beyond the time of initial set, results in higher tests. Five minutes is the time of mixing quite generally adopted in European specifications. The briquettes are to be made as prescribed for neat mixtures.

Portland cements require water from 11 to 12½ per cent by weight of constituent sand and cement for maximum strength in tested briquettes.

Puzzolan, about 9 to 10 per cent.

Natural, about 15 to 17 per cent.

Mixtures that a first appear too dry for testing purposes often become more plastic under the prolonged working required herein.

In general, about four briquettes constitute the maximum number that may be made well within the time required for initial setting of moderately slow setting cements.

Three such batches of sand mixtures should be made, and one briquette of each batch may be broken at seven and twenty-eight days, giving three tests at each period. At least one batch of neat cement briquettes should be made.

If the first briquette broken at each date fulfills the mini-

mum requirement of these specifications it is not necessary to break others which may be reserved for long-time tests.

If the first briquette does not pass the test for tensile strength, then briquettes may be broken until six briquettes, two from each batch, have been broken at seven days, and the remaining six reserved for twenty-eight-day tests. The highest result from any sample is to be taken as the strength of the sample when the break is at the least section of briquette.

If, on the twenty-eight-day tests, the cement not only more than fulfills the minimum requirements of these specifications, but also shows unusual gain in strength, it may still be accepted if the other tests are satisfactory, notwithstanding a low seven-day, test, if early strength is not a matter of importance. Such cements are likely to be permanent.

For a batch of four briquettes, the following quantities are suggested as in accord with these specifications. Water is measured by fluid-ounce volumes, not by weight, temperature varying not more than 10 degrees from 62 degrees F.

Portland Cement.

Neat.—20 ounces of cement, 4 ounces of water. Mix wet five minutes.

Sand.—15 ounces sand, 5 ounces cement, 2½ ounces water. Mix thoroughly dry; then mix wet five minutes.

Puzzolan Cement.

Neat.—20 ounces cement, 3¾ ounces water. Mix wet five minutes.

Sand.—15 ounces sand, 5 ounces cement, 2 ounces water. Mix thoroughly dry; then mix wet five minutes.

Natural Cement.

Neat.—20 ounces cement, 6 ounces water. Mix wet five minutes.

Sand.—10 ounces cement, 10 ounces sand, 3½ ounces water. Mix dry; then wet for five minutes.

For measuring tensile strength, a machine that applies the stress automatically at a uniform rate is preferable to one controlled entirely by hand.

These specifications for tensile strength contemplate the applications of stress at the rate of 400 pounds per minute to briquettes made as prescribed herein. A rate so rapid as to approximate a blow or so slow as to approximate a continued stress will give very different results.

The tests for tensile strength are to be made immediately after taking from the water or while the briquettes are still

wet. The temperature of the water during immersion should be maintained as nearly constant as practicable; not less than 50 degrees nor more than 70 degrees F.

The tests are to be made upon briquettes 1 inch square at place of rupture. The specifications contemplate the use of the form of briquette recommended by the committee of the American Society of Civil Engineers, held when tested by close-fitting metal clips, without rubber or other yielding contacts. The breaks considered in the tests are to be those occurring at the smallest section, 1 inch square.

SIMPLE TESTS.

Tests of cement received upon a work in progress must often be of much simpler character than prescribed herein.

Tests on the work are mainly to ascertain whether the article supplied is genuine cement, of a brand previously tested and accepted, and whether it is a reasonably sound and active cement that will set hard in the desired time, and give a good, hard mortar. Simple tests may give this information, and such should be multiplied whether or not more elaborate tests be made. Pats and balls of cement and mortar from the storehouse and mixing platform or machine should be frequently made. The setting or hardening qualities, as determined roughly by estimating time and by pressure of the thumbnail, should be observed; the hardness of the set and strength, by cracking the hardened pats or cakes between the fingers, and by dropping the balls from the height of the arm upon a pavement or stone and observing the result of the impact.

By placing the pats in water as soon as hardened sufficiently and raising the temperature to the boiling point for a few hours and observing the character and color of the fracture after sufficient immersion, information as to the character of the material, whether hydraulic, a Portland or Puzzolan, whether too fresh or possibly "blowy," may be speedily and quite well ascertained without measuring instruments.

Many engineers and users of cement regard such simple tests, taken in connection with the weight and fineness of the cement and the apparent texture and hardness of the mortars and concretes in the work, sufficient field tests of a material of known repute. The more elaborate tests, described above, should be made in well equipped laboratories by skilled cement testers.

CLASSIFICATION OF TESTS

The tests to be made are two classes:

(1) Purchase tests on samples furnished by bidders to ascertain whether the bidder may be held on the sample to the

delivery of suitable material, should his offer be accepted.

(2) Acceptance tests on samples taken at random from deliveries, to ascertain whether the material supplied accords with the purchase sample, or is suitable for the purpose of the work, as stated in the specifications for cement supplies.

(1) *Purchase Tests.*—Under these specifications bids for Portland cements will be restricted to brands that have been approved after at least three years' exposure in successful use under similar conditions to those of the proposed work. This specification limits proposals to manufacturers of cements of established repute, and in so far lessens the dependence to be placed upon tests of single samples of cement in determining the probable quality of the cements offered, that sample packages may not be required with the proposals when the brand is known to the purchaser. When the cement is not known to the purchasing officer by previous use, a barrel of it should be required as representing the quality of cement to be supplied. A full set of tests should be made from this sample, and subsequent deliveries be required to show quality at least equal to the sample.

In this connection it is advisable in districts where well-equipped laboratories have been established, that sample packages of the cements in use in that territory, as sold in the open market, be obtained and tested as occasion offers to ascertain the characteristic qualities of the brands as commercial articles, the information to be used in subsequent purchases of cements.

When purchase samples are waived, acceptance tests should be based upon the known qualities of the brand, as shown by previous tests.

The sample barrel should not be broken further than to take therefrom the necessary samples for testing. Afterwards it should be put away in a dry place and kept for further testing, should the results obtained be disputed.

(2) *Acceptance Tests.*—The tests to be made on cements delivered under contract depend not only on the extent, character, and importance of the work itself, but also on the time available between the delivery and the actual use of the material.

(*a*) On very important and extensive works, equipped with a testing laboratory and adequate storehouses, where cement may be kept at least thirty days before being required for use, full and elaborate tests should be made, keeping in view the fact that careful tests of few samples are more valuable than hurried tests of many samples.

(*b*) On active works of ordinary character, when time will not permit full tests, and on small works where the expenses of a laboratory are not justified, the tests must neces-

sarily be limited to such reasonable precautions against the acceptance and use of unfit material as may be taken in the usually short interval between the receipt and use of the material.

Such conditions were in view in formulating the specification that proposals will be received from manufacturers of such cements only as have been proved by at least three years' use under similar conditions of exposure. Of the tests named in the specifications those for fineness, activity or hydraulicity, specific gravity, weight of packages, and accelerated tests for indications as to soundness, may be made within two days after the receipt of the material and with a very small outlay for instruments.

Cement of established repute, shown by specific gravity and fineness to be properly burnt and ground, or normal for the brand, that will set hard in reasonable time, the cakes, snapping with a clean fracture when broken between the fingers, and standing the tests above named, may be accepted and used with reasonable certainty of success. Nevertheless, packages taken at random from the deliveries should occasionally be set aside and samples taken therefrom sent to a testing laboratory for the more elaborate tests for tensile strength (and for soundness should the boiling tests not be conclusive). The final acceptance and payment for such cement as may not have been actually placed in the work should, by agreement, be made to depend upon such tests.

In all cases where cement has been long stored it should be carefully tested before use to ascertain whether it has deteriorated in strength.

Should the simple tests give unsatisfactory or suspicious results, then a full series of tests should be carefully made.

When Portland cement is in question the specific gravity and fineness tests should be made to guard against adulteration, and in all cases test weighings should be made to guard against short weights.

In cases where the amount of cement or the importance of the work will not justify the purchase of the simple apparatus required for the specific gravity, fineness, and boiling tests, the cement can be accepted on the informal tests mentioned herein, which require no apparatus whatever, but in such cases cements well known to the purchaser by previous use should be selected, and purchased directly from the manufacturer or his selling agent in order that responsibility for the cement may be fixed.

Certified tests by professional inspectors made as prescribed herein on samples taken from the cement to be shipped to the work, in a manner analogous to that customary among

engineers in the purchase of structural steel and iron, may be required in such cases.

SAMPLING.

The entire package from parts of which tests are to be made is to be regarded as the sample tested. It should be marked with a distinctive mark that must also be applied to any part tested. The package should be set aside and protected against deterioration until all results from tests made from it are reached and accepted by both parties to the contract for supplies.

Cement drawn from several sample packages should not be mixed or mingled, but the individuality of each sample package should be preserved.

In testing it should be borne in mind that a few tests from any sample, carefully made, are more valuable than many made with less care.

The amount of material to be taken for formal tests is indicated herein where weights of the constituents of four briquettes are given, to which should be added the amount necessary for the tests for specific gravity, activity, and soundness.

In extended tests the material should be taken from the sample package from the heads and center of barrel, and from the ends and center of bag, by such an instrument as is used by inspectors of flour. All materials taken from the same sample package may be thoroughly mixed or mingled and the tests be made therefrom as showing the true character of the contents of the sample package.

In making formal tests at the work for acceptance of cement sample packages should be taken at random from among sound packages. The number taken must depend upon the importance and character of the work, the available time, and the capacity of the permanent laboratory force. For tensile strength the tests with sand are considered the more important and should always be made. Tests neat should be made if time permits.

It is not necessary in any case on a large work to test more than 10 per cent of the deliveries, even of doubtful cement, and a much less number of samples may be taken should no cause for distrust be revealed by the tests made. In very important work of small extent each package may be tested. A cement should be rejected if the samples show dangerous variation in quality or lack of care in manufacture and resulting lack of uniformity in the product without regard to the proportion of failures among samples tested.

In all cases in the use of cements the informal or simple tests of the character named herein should be constantly carried

on. These constitute most valuable tests. Whenever any faulty material is indicated by such tests, elaborate tests should be at once instituted and should the fault be confirmed, the cement delivered and not used should be rejected and the use of the brand be discontinued.

TESTS FOR WEIGHT.

From time to time packages should be weighed in gross and afterwards the weight of neat cement and tare of the packages determined. If short weight of neat cement is indicated, a sufficient number of packages should be weighed and the average net weight per package ascertained with sufficient certainty to afford a satisfactory basis of settlement.

RECORDS.

For tests at professional laboratories no general requirements as to records seem to be necessary. Each laboratory has its own blanks with certificate, and if a copy of the specifications be sent with the samples, the record returned should be sufficient. For records of formal tests on the work, or in a district laboratory, blank forms should be used. It is desirable to have the specification requirements stated on the form. Notations should be adopted to show for each test that the cement passed or failed or that the test was not made. No inference should be drawn from the lack of any entry other than that the recorder has neglected his duty.

SILICA CEMENT OR SAND CEMENT.

This is a patented article manufactured by grinding together silica or clean sand with Portland cement, by which process the original cementing material is made extremely fine and its capacity to cover surfaces of concrete aggregates is much increased. The sand is an adulteration, but on account of the extreme fineness of the product it serves to make mortar or concrete containing a given proportion of pure cement much more dense, the fine material being increased in volume.

The increase in cementing capacity due to the fine grinding of the cement constituent offsets, in great degree, the effects of the sand adulteration, so that sand cement made from equal weights of cement and sand approximates in tensile strength to the neat cement and the material is sold as cement.

The extreme fine grinding also improves cement that contains expansives, but nevertheless sand cement should not be purchased in the market, but should be made on the work from approved materials, if used for other purposes than for grouting, for which it is peculiarly adapted.

Whether this material should be used in important works for mortar and concrete, the Board considers a question of cost and expediency.

Over against the saving in cement may be placed the royalty on a patented article, the cost of the plant and of manufacture, the inconvenience of attaching a manufacturing establishment to a work under construction, and other elements bearing not only on first cost of cementing material but also involving the element of time. When cement is high priced, means of transportation limited, labor, sand, and concrete materials cheap and abundant, the conditions may justify the use of sand cement on economic grounds. In any case, the cement from which the product is made should be tested precisely as other cements.

SLAG CEMENT.

This term is applied to cement made by intimately mixing by grinding together granulated blast-furnace slag of a certain quality and slaked lime, without calcination subsequent to the mixing. This is the only cement of the Puzzolan class to be found in our markets (often branded as Portland), and as true Portland cement is now made having slag for its hydraulic base, the term "slag cement" should be dropped and the generic term ts and specifications for such cements.

Puzzolan cement made from slag is characterized physically by its light lilac color; the absence of grit attending fine grinding and the extreme subdivision of its slaked lime element; its low specific gravity (2.6 to 2.8) compared with Portland (3 to 3.5); and by the intense bluish green color in the fresh fracture after long submersion in water, due to the presence of sulphides, which color fades after exposure to dry air.

The oxidation of sulphides in dry air is destructive of Puzzolan cement mortars and concretes so exposed. Puzzolan is usually very finely ground, and when not treated with soda sets more slowly than Portland. It stands storage well, but cements treated with soda to quicken setting become again very slow setting from the carbonization of the soda (as well as the lime) element after long storage.

Puzzolan cement properly made contains no free or anhydrous lime, does not warp or swell, but is liable to fail from cracking and shrinking (at the surface only) in dry air.

Mortars and concretes made from Puzzolan approximate in tensile strength similar mixtures of Portland cement, but their resistance to crushing is less, the ratio of crushing to tensile strength being about 6 or 7 to 1 for Puzzolan and 9 to 11

to 1 for Portland. On account of its extreme fine grinding Puzzolan often gives nearly as great tensile strength in 3 to 1 mixtures as neat.

Puzzolan permanently assimilates but little water compared with Portland, its lime being already hydrated. It should be used in comparatively dry mixtures well rammed, but while requiring little water for chemical reactions, it requires for permanency in the air constant or continuous moisture.

PROPER USES OF PUZZOLAN CEMENT.

Puzzolan cement never becomes extremely hard like Portland, but Puzzolan mortars and concretes are tougher or less brittle than Portland.

The cement is well adapted for use in sea water, and generally in all positions where constantly exposed to moisture, such as in foundations of buildings, sewers and drains, and underground works generally, and in the interior of heavy masses of masonry or concrete.

It is unfit for use when subjected to mechanical wear, attrition, or blows. It should never be used where it may be exposed for long periods to dry air, even after it has well set. It will turn white and disintegrate, due to the oxidation of its sulphides at the surface under such exposure.

Specifications for Portland, Natural, and Puzzolan cement are appended hereto.

Respectfully submitted.

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SPECIFICATIONS FOR AMERICAN PORTLAND CEMENT.

(1) The cement shall be an American Portland, dry and free from lumps. By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product.

(2) The cement shall be put up in strong, sound barrels well lined with paper, so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not established itself as a high-grade Portland cement and has not for three years or more given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade Portland cement which have been made by the same mill and in successful use under similar climatic conditions to those of the proposed work for at least three years.)

(5) The average weight per barrel shall not be less than 375 pounds net. Four sacks shall contain one barrel of cement. If the weight, as determined by test weighings, is found to be below 375 pounds per barrel, the cement may be rejected, or at the option of the engineer officer in charge, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, specific gravity, soundness, time of setting, and tensile strength of the cement.

(7) *Fineness.*—Ninty-two per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) *Specific Gravity.*—The specific gravity of the cement, as determined from a sample which has been carefully dried, shall be between 3.10 and 3.25.

(9) *Soundness.*—To test the soundness of the cement, at least two pats of neat cement mixed for five minutes with 20 per cent of water by weight shall be made on glass, each pat about 3 inches in diameter and one-half inch thick at the center, tapering thence to a thin edge. The pats are to be kept under a wet cloth until finally set, when one is to be placed in fresh water for twenty-eight days. The second pat will be placed in water which will be raised to the boiling point for six hours, then allowed to cool. Neither should show distortion or cracks.

The boiling test may or may not reject at the option of the engineer officer in charge.

(10) *Time of Setting.*—The cement shall not acquire its initial set in less than forty-five minutes and must have acquired its final set in ten hours.

(The following paragraph will be substituted for the above in case a quick-setting cement is desired:

The cement shall not acquire its initial set in less than twenty nor more than thirty minutes, and must have acquired its finål set in not less than forty-five minutes nor in more than two and one-half hours.)

The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire one-twelfth inch in diameter loaded to weigh one-fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a wire one twenty-fourth inch in diameter loaded to weigh 1 pound.

(11) *Tensile Strength.*—Briquettes made of neat cement, after being kept in air for twenty-four hours under a wet cloth and the balance of the time in water, shall develop tensile strength per square inch as follows:

After seven days, 450 pounds; after twenty-eight days, 540 pounds.

Briquettes made of 1 part cement and 3 parts standard sand, by weight, shall develop tensile strength per square inch as follows:

After seven days, 140 pounds; after twenty-eight days, 220 pounds.

(In case quick-setting cement is desired, the following tensile strengths shall be substituted for the above:

Neat briquettes: After seven days, 400 pounds; after twenty-eight days, 480 pounds.

Briquettes of 1 part cement to 3 parts standard sand: After seven days, 120 pounds; after twenty-eight days, 180 pounds.)

(12) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(13) When making briquettes neat cement will be mixed with 20 per cent of water by weight, and sand and cement with $12\frac{1}{2}$ per cent of water by weight. After being thoroughly mixed and worked for five minutes, the cement or mortar will be placed in the briquette mold in four equal layers, and each layer rammed and compressed by thirty blows of a soft brass or

copper rammer three-quarters of an inch in diameter (or seven-tenths of an inch square, with rounded corners), weighing one pound. It is to be allowed to drop on the mixture from a height of about half an inch. When the ramming has been completed, the surplus cement shall be struck off and the final layer smoothed with a trowel held almost horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(14) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bidders will deliver a sample barrel for test before the opening of bids. If this sample shows higher tests than those given above, the average of tests made on subsequent shipments must come up to those found with the sample.

(15) A cement may be rejected in case it fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer in charge may, if he deem it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner herein specified. All expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

SPECIFICATIONS FOR NATURAL CEMENT.

(1) The cement shall be a freshly-packed natural or Rosendale, dry, and free from lumps. By Natural cement is meant one made by calcining natural rock at a heat below incipient fusion, and grinding the product to powder.

(2) The cement shall be put up in strong, sound barrels, well lined with paper so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade natural cement which have been in successful use under similar climatic conditions to those of the proposed work.)

(5) The average net weight per barrel shall not be less than 300 pounds. (West of the Allegheny Mountains this may be 265 pounds) . . . sacks of cement shall have the same weight as 1 barrel. If the average net weight, as determined by test weighings, is found to be below 300 pounds (265 pounds) per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply free of cost to the United States an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, time of setting, and tensile strength of the cement.

(7) *Fineness.*—At least 80 per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) *Time of Setting.*—The cement shall not acquire its initial set in less than twenty minutes and must have acquired its final set in four hours.

(9) The time of setting is to be determined from a pat of neat cement mixed for five minutes with 30 per cent of water by weight and kept under a wet cloth until finally set. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire one-twelfth inch in diameter loaded to weigh one-fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a wire one twenty-fourth inch in diameter loaded to weigh 1 pound.

(10) *Tensile Strength.*—Briquettes made of neat cement shall develop the following tensile strengths per square inch, after having been kept in air for twenty-four hours under a wet cloth and the balance of the time in water:

At the end of seven days, 90 pounds; at the end of twenty-eight days, 200 pounds.

Briquettes made of one part cement and one part standard sands by weight shall develop the following tensile strengths per square inch:

After seven days, 60 pounds; after twenty-eight days, 150 pounds.

(11) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any